R E Doherty

Electrical Engineering

July
1934

Published Monthly by the
American Institute of Electrical Engineers

Pacific Coast Convention—Salt Lake City, Utah—Sept. 3–7, 1934

Published Monthly by

American Institute of Electrical Engineers

(Founded May 13, 1884)

Electrical Engineering

Registered U. S. Patent Office

July 1934
Volume 53
No. 7

The Official Monthly Journal and Transactions of the A.I.E.E.

UBLICATION OFFICE, 20th and Northmpton Streets, Easton, Pa.

DITORIAL AND ADVERTISING OFFICES, 3 West 39th Street, New York, N. Y.

NTERED as second class matter at the Post Office, Easton, Pa., April 20, 1932, under the ct of Congress March 3, 1879. Accepted or mailing at special postage rates provided or in Section 1103, Act of October 3, 1917, uthorized on August 3, 1918.

UBSCRIPTION RATES—$12 per year to Inited States, Mexico, Cuba, Porto Rico, Hawaii and the Philippine Islands, Central America, South America, Haiti, Spain and panish Colonies; $13 to Canada; $14 to ll other countries. Single copy $1.50.

HANGE OF ADDRESS—requests must be eceived by the fifteenth of the month to be ffective with the succeeding issue. Copies ndelivered due to incorrect address cannot e replaced without charge. Be sure to pecify both old and new addresses and any hange in business affiliation.

DVERTISING COPY—changes must be reeived by the fifteenth of the month to be ffective for the issue of the month succeeding.

TATEMENTS and opinions given in articles ppearing in "Electrical Engineering" are the xpressions of contributors, for which the stitute assumes no responsibility. Correspondence is invited on all controversial atters.

LECTRICAL ENGINEERING is indexed in dustrial Arts Index and Engineering Index.

inted in the United States of America. umber of copies this issue—

17,700

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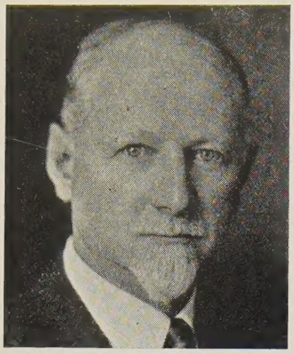
CORRECTION: The title of Prof. D. C. Jackson's contribution to the May 1934 50th anniversary issue of ELECTRICAL ENGINEERING should have read "The Evolution of Electrical Engineering Education" instead of "The Evolution of Electrical Engineering" as appears on p. 770 of that issue.

The Institute's National Officers Newly Elected for the Year 1934–35



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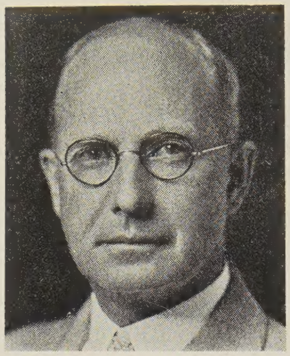

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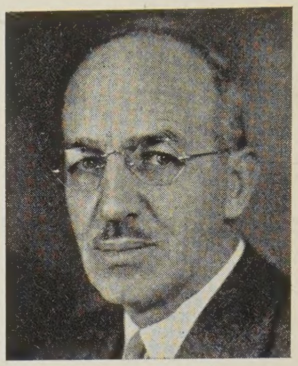

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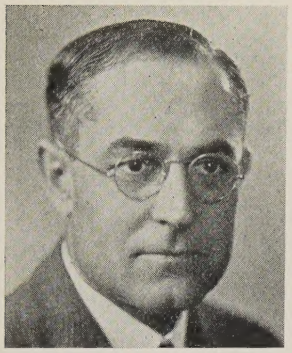

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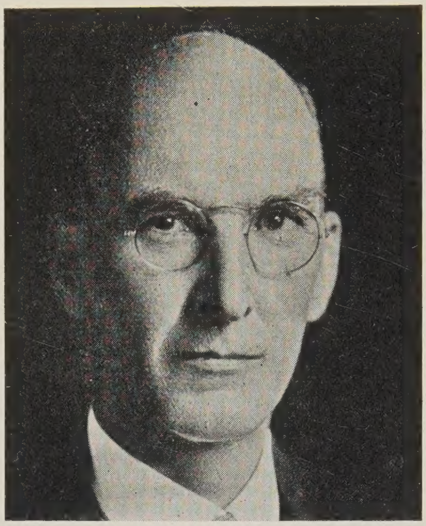

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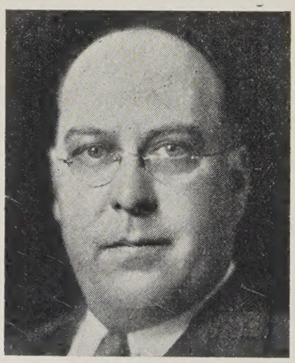

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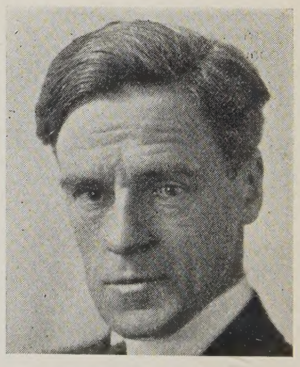

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An Insight Into the Workings of the Institute

By J. ALLEN JOHNSON, Vice President A.I.E.E.

The keynote behind the success of the Institute is the spirit of mutual helpfulness to other members and of disinterested service to humanity. That such a spirit motivates the large number of individuals who coöperate actively in the affairs of the Institute is brought out in the following discussion by President-Elect J. Allen Johnson. To the many members of the Institute who are not intimately familiar with its "workings" this article should be interesting and helpful.

THE "workings" of the Institute involve many types of activity, and to many members who are not familiar with all of these activities, the administration of the Institute by its officers, committee members, staff, and others, appears as something complicated and difficult to understand. Of course, nothing could be further from the truth, and it is hoped that this discussion may serve to dispel any such impression.

Now it appears that the Institute works the way it does because of what it is and consequently that consideration should first be given to what the Institute is before proceeding to a discussion of how it works.

What the Institute is is defined by its objects and its membership. According to its constitution its objects are "The Advancement of the theory and practice of Electrical Engineering and of the allied Arts and Sciences and the maintenance of a high professional standing among its members." Its membership comprises electrical engineers by profession, professors and other teachers of electrical engineering and electrical subjects, persons who have done notable original work in electrical science, and others engaged in electrical or closely allied work. The membership is classified into Honorary Members, Fellows, Members, and Associates. The requirements for admission to the several membership grades are specified in the constitution, and it may be assumed that all members are familiar with them.

Objects

Now as to the objects of the Institute, there are a number of points to which attention should be directed. The first point is that the objects, as stated, proceed from broad unselfish motives rather than from narrow selfish ones. They are directed toward general social progress rather than mere class advancement. To the extent that these objects are directed toward advancement of the Institute's membership they are directed toward their professional rather than their economic advancement. They are based upon the principle that engineering is a profession and thus proclaim their origin in the principle of "noblesse oblige" which acknowledges the obligation of the professional man unselfishly to devote to the good of the social order some part of the advantages which that social order has enabled him to obtain. This principle, it seems to me, must be firmly maintained as the guiding principle of a professional life.

This does not mean that the Institute may not concern itself at all with the economic status of its members. It may and it does, but it does seem clear that such concern must be secondary to the primary concern of "maintaining their high *professional* standing." The primary concern of a professional engineering society must be to make better engineers. Better engineers will result in better engineering; better engineering should result in a better world and a better world must necessarily result in a better and happier life for all, including of course the engineers themselves. Thus the Institute's stated objects seem to require that whatever the Institute may do to promote the economic advancement of its membership it must do in the spirit that such action will be for the benefit, rather than at the expense, of other social groups and society as a whole.

Membership

Now as to the membership, the first point to which attention should be called is that the Institute is a society of individual engineers. Engineering work is peculiarly individual work because it is very largely the product of imagination, which is inherently an individual characteristic. The Institute is composed therefore of peculiarly individual individuals.

As a second point regarding the Institute's membership, suppose we take a look at engineers and see what kind of people they are. In general, it appears, engineers become engineers because they are interested in the forces of nature and enjoy the ability which the study of engineering gives them to direct those forces "for the use and convenience of man." That is, to the extent that they share the normal human desire for power and influence, they satisfy that desire by exercising that power and influence over the physical forces of nature rather than over their fellow men. Furthermore, I believe that the desire for wealth is not a typical characteristic of the engineer. He expects his work to be properly evaluated and compensated in proportion to its worth, but he is, in general, a sane and modest chap and has no delusions of grandeur or exaggerated idea of his importance in the social scheme. Possibly he is unduly modest and underrates his value but if so he gets his compensation in the pleasure he derives

Essentially full text of an address presented at the A.I.E.E. North Eastern District meeting, Worcester, Mass., May 16–18, 1934. *Not published in pamphlet form.*

from his work, and he is fortunate in having a kind of work to do in which he can take pleasure. That fact is one good reason why he owes something to the social order which has made it possible for him to acquire the knowledge which enables him to do interesting and pleasurable work. In that respect, at least, he has the advantage over the great majority of human beings. It is possible that when engineers, as they occasionally do, become unduly concerned in regard to their economic status as compared to other working groups, they forget this great advantage that they possess over most of those with whom they compare themselves. If so, they should remind themselves of it.

It is true, of course, that in times of economic stress, many engineers, in common with many workers in less attractive fields, are forced out of employment. Under such circumstances it is the duty of other engineers more fortunately situated to rally to their assistance. The engineer whom you help in time of trouble may be the very one who, in better days, provided you with an idea or an inspiration by way of the free exchange which takes place through the Institute, which enabled you to gain or hold the job which you have. Through your mere continued membership in the Institute, whether you know it or not, you have been of help to many unemployed engineers hard pressed during the recent depression, by enabling the Institute to be more lenient in the matter of delinquent dues.

Well, what has all this to do, you say, with the workings of the Institute? It has this to do. There are certain things the Institute can consistently do because it is what it is and because its members are what they are. There are certain other things the Institute cannot consistently do because it is not what it is not. It is not a labor union. It is not an organization of class conscious workers for the purpose of promoting their own economic self-interest. It cannot call a strike of its members in order to force an increase in their compensation. Probably no Institute member ever thought of such a thing, but nevertheless the Institute has been criticized on the ground that it hasn't done enough for the economic advantage of its members. The answer of course is that that is not what the Institute is for.

The prime function of the Institute, so far as its members are concerned is and always must be that of promoting their technical, professional, intellectual, cultural, and social advancement. It cannot consistently concern itself primarily with their economic condition as a class.

There is still another reason why a specialized engineering society like the A.I.E.E. cannot make the economic status of its members its primary concern. Engineering is *one* profession, not *many*. Its members may, and indeed must, specialize, to which fact the number of engineering societies amply testifies, but specialists though they be, they are engineers first and specialists afterward. When, therefore, such a specialized engineering group as the A.I.E.E. finds that it *must* act in the interest of the economic status of its members, the solidarity of the engineering profession requires that it do so through some joint agency with other engineering societies. As a matter of fact, the Institute does engage in certain activities of this character, which will be mentioned later on.

It was stated at the beginning that the Institute works the way it does because of what it is and an attempt has been made in the foregoing to give an interpretation of what the Institute is and why. We may now proceed to a discussion of "its workings."

Institute Management

In the first place, since the Institute is an organization of individuals, it must of course be and it is, a democratic institution. Every corporate member of the Institute, of whatever grade, has an equal right to vote. Its method of nominating and electing its officers is also thoroughly representative and democratic. Let us see how this is so.

The management of the Institute, as you know, is vested in a board of directors. This board consists of a president, 2 junior past-presidents, 10 vice presidents, 12 directors, and a treasurer. The national secretary also serves as secretary to the board but is not a member of it. The 10 vice presidents represent, respectively, the 10 geographic Districts and the nomination and election procedure is such that each District vice president is nominated by his own district. The president serves for 1 year, vice presidents serve for 2 years. The 12 directors are chosen at large, 3 being nominated and elected each year and they serve for 4 years.

Nomination of Officers

The nominating procedure is thoroughly democratic. Each Section chooses its own officers. Section chairmen and secretaries constitute the District executive committees. The national nominating committee consists of one representative from each geographic District, elected by its executive committee, and other members, not exceeding in number the number of geographic Districts, chosen by and from the board of directors. As a matter of fact, the board of directors has voluntarily limited its representation on the nominating committee to $^1/_2$ the number of geographic Districts so that as a matter of practice the nominating committee is dominated by the representatives of the geographic Districts and not at all by the board of directors. It is thus quite impossible for the board of directors to perpetuate itself or to "hand pick" the nominees even if it wanted to do so. The national nominating committee has nothing whatever to say about the nominations for vice presidents (of which 5 are elected each year) unless some District fails to nominate a candidate within the time provided by the by-laws, in which event the national nominating committee is empowered to act. The national nominating committee itself nominates only a candidate for president, 3 candidates for directors, and 1 candidate for national treasurer. The constitution provides that independent nominations may be made by the petition of 25 or more members sent to the national secretary, and that such petitions for the

nomination of a vice president shall be signed only by members within the District concerned. Thus, if any group of 25 or more members is dissatisfied with the candidates nominated by the District executive committee, or by the national nominating committee, they are entirely free to nominate independent candidates. The fact, however, that this is so seldom done is in itself an acknowledgment of the fairness and truly representative character of the nominating and election procedure as it now exists.

Summarizing, the national nominating committee of 15 includes only 5 members selected by the board of directors and this committee nominates only $^1/_2$ of the officers to be elected each year. Under these circumstances it seems quite clear that no small group can possibly control the nominations. The men who from year to year are chosen to the board of directors by this procedure, are of high caliber, and serve with unselfish devotion. They take their jobs seriously and render to the Institute a quality of service which does not in any degree suffer from the fact that it is rendered without pay.

Joint Activities of the Institute

The activities in which the Institute engages are many and various. These activities may be considered to be divided roughly into 2 classifications; first, internal activities primarily for the benefit of its own membership; second, joint and coöperative activities primarily for the benefit of the engineering profession, the country, and the world at large. The second group will be first briefly outlined and discussed. This group includes the following:

1. United Engineering Trustees, Inc., including Engineering Foundation and Engineering Societies Library
2. American Standards Association, including the Electrical Standards Committee, and the United States national committee of the International Electrotechnical Commission
3. Engineering Societies Employment Service
4. The American Engineering Council
5. The Engineers' Council for Professional Development

United Engineering Trustees, Inc.

The United Engineering Society, now known as United Engineering Trustees, Inc., was created in 1904 by the American Institute of Mining and Metallurgical Engineers, The American Society of Mechanical Engineers, and the American Institute of Electrical Engineers, to hold and administer for them jointly real estate and funds, "to advance the engineering arts and sciences in all their branches, and to maintain a free public engineering library." The American Society of Civil Engineers became a member of the group in 1916. Each society has 3 representatives on the board of trustees.

The United Engineering Trustees, Inc., holds the United Engineering Societies Building at 29–33 West 39th Street, New York City, and each founder society is assessed by the U.E.T., Inc., for building operation and maintenance in proportion to the amount of space occupied and pays additional amounts for actual use of the auditorium, other meeting rooms, public address system, etc. The present Institute budget contains an allowance of $3,000 for the building assessment. For the year which ended September 30, 1931, the actual payments amounted to $5,713.66.

The United Engineering Trustees, Inc., also holds the principal of the gifts of Doctor Swasey and others to the Engineering Foundation for safe-keeping and administration, but the net incomes are administered by the Engineering Foundation board.

Engineering Foundation

The Engineering Foundation is a joint agency of the founder societies "for the furtherance of research in engineering or for the advancement in any other manner of the profession of engineering and the good of mankind." It devotes its research to human as well as technical aspects of engineering problems of wide interest. The Foundation's aid to the advancement of the profession extends to activities aimed at both understanding and application of natural laws fundamental to both physics and ethics. Coöperation and effectiveness are keynotes of the Foundation's policies. They are personal traits of its founder, Dr. Ambrose Swasey, of Cleveland, Ohio.

The Institute makes no financial contributions to the Foundation's work; on the contrary, the Foundation furnishes assistance in connection with researches recommended by the Institute and other societies. During the past several years, it has supplied substantial financial assistance for 2 researches sponsored by our committee on electric welding, one at Massachusetts Institute of Technology and the other at Lehigh University. The former has been completed, and the latter is being continued.

The Engineering Foundation board, which administers the net incomes of funds set aside for its use, is composed of 16 members, including 2 representatives of each of the founder societies, 4 representatives of the United Engineering Trustees, Inc., 3 members at large, and the president of U.E.T., Inc., *ex-officio.*

Engineering Societies Library

The Engineering Societies Library, to the extent that it is not self-supporting, is supported by contributions from the 4 founder societies on the basis of an equal contribution from each plus an additional contribution from each society based upon its membership. The library board consists of 21 members: 4 appointed representatives of each society, the secretary of each society, and the director of the library.

American Standards Association

The American Standards Association, formerly known as the American Engineering Standards Committee, was organized in 1918 by the A.I.E.E. and 4 other societies. The American Standards Association is now composed of about 200 member

bodies. The Institute has representatives on many of the Association's committees and is sponsor or joint sponsor under the A.S.A. for a large number of standardization projects.

Under the A.S.A. procedure, all proposed electrical standards are referred to the association's Electrical Standards Committee on which the Institute is directly represented by 3 members with an alternate. There are many other individual members of the Institute on the Electrical Standards Committee as representative of various other groups, such as the electric light and power group and the National Electrical Manufacturers' Association.

The Electrical Standards Committee on which the Institute is thus largely represented also serves, with the addition of representatives from the American Society of Mechanical Engineers and a number of members at large (most of whom are also members of the Institute), as the U.S. national committee of the International Electrotechnical Commission, which is the agency through which international standardization projects in the electrical field are coordinated with American standards and practices.

Engineering Societies Employment Service

The Institute coöperates with the national societies of civil, mining, and mechanical engineers in the operation of the Engineering Societies Employment service with its main office in the Engineering Societies Building, New York. Offices are operated in Chicago and San Francisco also. In addition to the societies named, others coöperate in certain of the offices as follows: New York, Society of Naval Architects and Marine Engineers; Chicago, Western Society of Engineers; San Francisco, California Section of the American Chemical Society, and the Engineers' Club of San Francisco.

The New York office has been coöperating closely with the Professional Engineers Committee on Unemployment which was organized in the fall of 1931 by the local Sections of the A.S.C.E., A.I.M.E., A.S.M.E., and A.I.E.E.

The service is supported by the joint contributions of the societies and their individual members who are benefited. As in the past, it consists principally in acting as a medium for bringing together the employer and the employee. In addition to the publication of the employment service announcement monthly in Electrical Engineering, weekly subscription bulletins are issued for those seeking positions.

In 1929, the service was on a practically self-supporting basis, but as the number of positions available declined, and as a smaller percentage of the members placed were able to make the expected contributions toward the operating costs, it became necessary for the societies to increase their appropriations, as well as to reduce the costs of operation of the service.

The appropriations of the societies have for years been adjusted according to the numbers of placements among their respective members.

For the year ending September 30, 1931, the Institute expended for this service $1,226.22, and for the present budget year it has appropriated $4,000. The service is supervised by a committee composed of the secretaries of the 4 societies.

Prior to the establishment of the joint employment service, the staff of each society furnished assistance to its members who were seeking positions. Many members expect their society to make special efforts to secure positions for them, and the joint service has been more economical and satisfactory than the previous arrangement. It is certain that if the joint service were not available members of the Institute headquarters staff would find it necessary to spend far more time on employment matters.

(For an analysis of recent accomplishments of the Engineering Societies' Employment Service, see Table XI of the report of the Institute's board of directors for the fiscal year ending April 30, 1934, p. 1095–1107, this issue.)

American Engineering Council

The "object" of the American Engineering Council, as stated in its consitution, is "to further the public welfare wherever technical and engineering knowledge and experience are involved, and to consider and act upon matters of common concern to the engineering and allied technical professions."

The Council includes in its membership about 20 national, state, and local engineering societies and maintains it headquarters at Washington, D. C. Under the plan of reorganization recently adopted for the purpose of making further drastic reductions in the operating expenses of the Council, the assembly and the administrative board were combined, and the numbers of representatives reduced. The A.S.C.E., A.S.M.E., and the Institute now have 5 representatives each, 2 other societies have one each, and there are 6 regional representatives for state and local societies. In addition, past-presidents of Council serve for 6 years after the expiration of their terms as president without being accredited to any member organization.

It is interesting to note that 2 former members of the Institute board of directors were elected officers of the Council for 1934: C. O. Bickelhaupt, vice-president, and C. E. Stephens, treasurer. Our Past-President William McClellan is chairman of the finance committee, and hence is a member of the executive committee which is composed of the elected officers and the chairman of the finance committee.

Some of tbe subjects considered by the assembly-administrative board in January are:

Transfer of coast and geodetic survey to Navy Department

Employment conditions for engineers imposed by the Federal Government

Federal public works policy, governmental competition

Securities Act of 1933

Telephone directory classification of engineers

The wide variety of types of activities in which the Council engages is illustrated by the titles of the special committees which have been continued for 1934, as follows:

Administration of public works

Air transport service in foreign commerce

Communications

Competition of governmental agencies with engineers in private practice

Engineers' water power policy

Flood control

Naval towing tank

Patents

Relation of consumption, production, and distribution

State engineering councils

Telephone directory classification of engineers

Water resources

Committee to appear before coördination committee of founder societies

In his annual report, presented in January, L. W. Wallace, who resigned at that time as executive secretary, stated that in no like period in the Council's history had its assistance been sought as much as during 1933, and specifically after March 4. A large number of the Federal agencies called upon it for advice and for recommendations of engineers for many types of work. The Council has endeavored in so far as possible to protect the well-being of the engineering profession by encouraging any desirable developments and opposing those which were considered to be against the public welfare.

F. M. Feiker, who succeeded Mr. Wallace as executive secretary, in January, is anxious to have the Council become known as the "Washington Embassy" for engineers and engineering, and is intensively seeking ways in which it can most effectively serve the engineering profession and through it the public welfare.

Engineers' Council for Professional Development

This activity is undoubtedly the most important and far reaching movement for the advancement of the professional standing of engineers which has ever taken place. The following discussion of it is taken largely from the Council's first annual report, published Dec. 4, 1933.

The Engineers' Council for Professional Development, a new agency of the engineering profession, was brought into being in October 1932, by joint authorization of the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers, The American Society of Mechanical Engineers, the American Institute of Electrical Engineers, the American Institute of Chemical Engineers, the Society for the Promotion of Engineering Education, and the National Council of State Boards of Engineering Examiners.

The Council consists of 21 members, 3 from each of the participating bodies, from whom a chairman is elected, and a secretary, who need not be one of the representatives. Its purpose is the enhancement of the professional status of the engineer. To this end, it aims to coördinate and promote efforts and aspirations directed toward the higher professional standards of education and practice, greater solidarity of the profession, and greater effectiveness in dealing with technical, social, and economic problems. Its immediate objective is the development of a system whereby the progress of the young engineer toward professional standing can be recognized by the public, by the profession, and by the man himself through the development of technical and other qualifications which will enable him to meet minimum professional standards.

E.C.P.D. functions by studying questions within the range of its objectives, and making recommendations from time to time to the governing boards of the participating societies as to procedures that are considered of value in promoting such objectives. It will administer only such procedures as have been approved by the boards of the participating societies and assigned to it.

During its first year, the Engineers' Council for Professional Development perfected its organization and made far-reaching recommendations including (1) a program for accrediting engineering schools, (2) a minimum definition of the engineer, and (3) a suggested scheme looking to greater uniformity in the grades of membership in the professional societies. The Council has 4 standing committees.

The function of the committee on student selection and guidance is to report to E.C.P.D. schemes for the educational and vocational orientation of young men with respect to the characteristics of an engineering education and the responsibilities and opportunities of engineers in order that only those who have the high qualities, aptitude, and capacity required to obtain intellectual satisfaction therefrom may seek entrance to such courses.

The duties of the committee on engineering schools are to report to E.C.P.D. means for bringing about coöperation between the engineering profession and the engineering schools. As a first step in its activity, the committee has the duty of reporting to the Council criteria for colleges of engineering which will insure to their graduates a sound educational foundation for the practice of engineering. The Council voted to approve the recommendations of this committee and to recommend to the participating bodies that E.C.P.D. be set up as an accrediting agency for schools of engineering.

The duties of the committee on professional training are to report to E.C.P.D. plans for the further personal and professional development of young engineering graduates and young men entering the profession without formal scholastic training.

The committee on professional recognition is charged with the duty of reporting to E.C.P.D. methods whereby engineers who have met suitable standards may receive corresponding professional recognition. Upon recommendation of the committee, E.C.P.D. approved a definite policy as a guide in fulfilling the committee's purpose. This policy was outlined in an article "E.C.P.D. Committee on Professional Recognition Commented Upon by C. N. Lauer and Dean Barker," appearing in Electrical Engineering for January 1934, p. 224–5. This program involves selection of proper material, its supervised education, intimate contact with the profession during the apprenticeship stage, and the

attainment of definite specified educational requirements with concurrent recognition by professional societies, educational institutions, and state laws. The committee also has formulated a definition of an "engineer" which was approved by E.C.P.D., which voted to transmit it to the participating bodies for their discussion and approval. These minimum qualifications for an engineer also were given in the previously mentioned article in the January issue. At a recent meeting this committee adopted and recommended for approval "a practical program of certification covering the transition period, with progressive adjustment of requirements and successive tightening of standards, always keeping in view, as a goal, the early complete effectuation of the E.C.P.D. standards and program of individual certification as applied to new members of the profession."

It should be clearly understood that this program of E.C.P.D. is still in the formative stage and has not as yet been approved for adoption by the several sponsoring organizations. It cannot be adopted until it has the approval of the governing boards of all of those organizations. The proposals are receiving most careful and thorough consideration by the Institute's board of directors, but it would, of course, be premature to predict at this time what action the board will take. However, faced as we are, in many States, with licensing legislation, a uniform definition of an "engineer" and uniform procedures for certifying their eligibility appear highly desirable if a condition of chaos is to be avoided, and the professional standing of qualified engineers is to be uniformly recognized.

The problem of financing these activities has still to be worked out, but it is thought that they can be made self-supporting and at a social cost much less than would result from the alternative chaotic situation. It is not anticipated that the program will involve any direct expense to the Institute.

Internal Activities of the Institute

A lengthy discussion of Institute activities with which members are all familiar, such as its meetings, its publications, and its geographical District, Section, and Branch activities, is not included here. There are however 2 internal activities with which the membership at large have comparatively little direct contact, but whose personnel carry heavy responsibilities in promoting the effectiveness of the Institute in its service to its members. These are the Institute's committees and its headquarters staff.

There are 2 groups of standing committees.

General Committees

The general committees include the executive and finance committees and the board of examiners provided by the constitution, and 15 other committees dealing with the following subjects: technical programs, publications, coördination of Institute Activities, Sections, constitution and by-laws, Institute policy, headquarters, membership, standards, Edison medal, Lamme medal, award of Institute prizes, safety codes, code of principles of professional conduct, and Student Branches. In addition to these standing committees, special committees are appointed from time to time to consider matters not within the scope of the standing committees.

Technical Committees

There are 18 technical committees on the following subjects: automatic stations, communication, education, electrical machinery, electric welding, electrochemistry and electrometallurgy, electrophysics, instruments and measurements, applications to iron and steel production, production and application of light, applications to marine work, power generation, power transmission and distribution, protective devices, research, and transportation.

Any attempt to visualize the tremendous mass of work performed by these committees must be left to the reader's imagination. Some of course are more active than others, but many of them hold several meetings a year, and many of them have subcommittees which also hold independent meetings. Much work is done also by correspondence. The personnel of the general committees comprises about 200 men and the technical committees about 375. There are some duplications in these numbers but on the other hand there are probably many others working on subcommittees who do not appear in the published lists. It is probably safe to say that from 500 to 600 Institute members are actively engaged in committee work.

We should all bear in mind that these 500 or 600 men who are giving of their knowledge, experience, and energy for the benefit of the entire membership, are just members like ourselves. They pay no less in dues than other members and they receive no monetary compensation whatever for their committee work; in fact, in many cases it causes them additional expense. In spite of these facts however, these 500 or 600 members who give their time and energy to committee work are the ones who are getting the most out of their Institute membership. This, however, does not alter the fact that the Institute and its members owe them a debt of gratitude. Without their contribution to its work the Institute could hardly function at all.

Of all the Institute committees, the one which has probably faced the most difficult task during the last 4 years has been the finance committee of which E. B. Meyer is chairman. The finance committee has the task of fitting the Institute's expenses to its income, and with the reduction which this income has undergone, this committee has had most difficult problems to solve. How some of these problems have been met Mr. Meyer has told in his article "The Story of the Institute Budget" in the March 1934 issue of ELECTRICAL ENGINEERING, p. 375–81. Every member who has not already done so should read and study Mr. Meyer's article. Every member of the Institute should understand its financial problems and how they are dealt with and especially so if he ever feels inclined to criticize the distribution of its income.

It is true that in the past the opportunities for participation in technical committee work have been somewhat limited. However, under the leadership of I. Melville Stein of Philadelphia, chairman of the Institute Sections committee, a definite plan for Section participation in technical committee work has been proposed and is scheduled for discussion at the conference of officers and delegates at the coming midsummer convention. The plan is outlined in the April 1934 issue of ELECTRICAL ENGINEERING, p. 631. The plan provides an opportunity for every Section member desiring to do so to participate in technical committee work, and is worthy of careful consideration by every member of the Institute.

The Headquarters Staff and Its Duties

On May 1, 1902, 18 years after its organization, the Institute had a membership of only 1,549, and was the smallest of the 4 societies of civil, electrical, mechanical, and mining engineers. The very rapid increase in membership, after the establishment in that year of the provisions for Sections and Branches, made it the largest of the 4 societies less than 5 years later (4,000 members). (It retained that distinction until 1915.) The rapid increase in membership, which continued at varying rates for many years and the accompanying expansions of the activities required the building up of a staff which would be able to render effectively all of the many types of services demanded of the headquarters of such a society.

With a membership of 3,027 in 1904 (May 1), the Institute had a staff of 10 persons. By 1917, the membership had increased to 8,710 (May 1) and the staff to 17. The membership of more than 18,000 which was maintained from the early part of 1926 until reductions were caused by the depression, and some further expansions in the activities, caused the total number of staff members to reach 36 in 1929.

On account of the decreased income, the acting national secretary and the office manager recommended some reductions in staff at the end of 1932, and did not fill a vacancy which occurred in 1933. These changes reduced the staff to a total number of 26. The reductions were made despite the fact that the revised publication plan required more persons in the editorial department than in 1929, and the fact that other essential parts of the work have been made materially heavier by the depression, notably correspondence regarding inability to pay dues, and the answering of many inquiries which result directly from the large amount of time many individuals have available.

Since 1904, the numbers of Sections and Branches have increased from 16 and 11, respectively, to 61 and 113. The number of committees has likewise been greatly increased, and the activities in general have been expanded in many directions.

Members of the staff carrying the principal responsibilities are:

H. H. Henline, national secretary

F. A. Norris, office manager

G. Ross Henninger, editor

H. E. Farrer, secretary, board of examiners
secretary, standards committee

C. A. Graef, advertising manager

C. S. Rich, secretary, technical program committee

Of these, it is worthy of note that Messrs. Henline and Henninger are Members and Messrs. Farrer and Rich Associates of the Institute.

In addition, there are 4 editorial workers, 3 of whom are Associates; 3 junior clerks who perform a wide variety of duties, including addressograph, mimeograph, mailing, stock, and messenger services; and 13 other persons who are engaged in the entire range of work required of the staff.

The duties of the staff embrace a mass of detail work in connection with ELECTRICAL ENGINEERING and the TRANSACTIONS, advertising, the Year Book, the 61 Sections and 113 Branches, general administration, joint activities, secretarial and other work for committees, etc. These duties include editing and proof-reading, correspondence, record keeping, billing, indexing, preparation of annual and other reports, mailing, interviewing, arranging for meetings and conventions, accounting, filing, shipping, assistance in preparation of budget, and others too numerous to mention. A mere catalog of the specific services required of the staff comprises over 4 typewritten pages.

It always has been the practice to keep the staff at the minimum number of persons required for performing the necessary duties. Accounting, members' records, correspondence, and all other parts of the work have been kept on the simplest possible basis. The variety of duties required of the limited staff makes it essential that the assignments be arranged on a flexible basis. No member of the staff is limited entirely to one particular type of work, except in editorial and advertising, but each has been thoroughly trained in other duties, and practically all have had years of experience in Institute methods. Consequently, the distribution of duties can readily be shifted from day to day, and the services can be maintained with a minimum payroll cost per member of the Institute.

That the Institute is not overstaffed is indicated by a recent comparison of the staffs of the 4 large national engineering societies, which shows the following:

	A.I.E.E.	A.S.C.E.	A.I.M.E.	A.S.M.E.
Total number of employees	26	52	23	63

Sections and Branches

Before concluding, a few statements should be made regarding the relationship of the Sections and Student Branches to the Institute. Student enrollment in the Institute was initiated in order that the young men training to become engineers might be kept informed as to the latest developments in the various fields of electrical engineering, so that their transition from student life to professional life might be made gradually rather than abruptly. It was felt that, by this means, these young men would be greatly assisted in "finding themselves"

in the professional field, thereby not only accelerating their individual professional progress but also enhancing the standing of the profession as a whole. That this purpose is being accomplished will be readily admitted by any one who has attended a Student session at any of our meetings. The provision of student meetings conducted on a professional basis by the Branches can add tremendously to the effectiveness of this development. The very moderate fees paid by Enrolled Students obviously do not cover the entire cost of this service, which includes sending ELECTRICAL ENGINEERING to each Enrolled Student, but the Institute has faith that the bread so cast upon the waters will return again after many days in the form of an enthusiastic membership imbued with the professional spirit. I think there is no service which the Institute renders that is more worth while.

Now as to the Sections; they were organized in order that a larger proportion of the Institute membership might have the opportunity, by meeting together, to promote the objectives of the Institute. These objectives imply, as already pointed out, an attitude of unselfish service to the profession, to the nation, and to the world. Now not all members of the Institute are fortunate enough to be able to participate in Section activities. Only about $^2/_3$ of the membership even resides in Section territory. Section members and officers might do well to remember this fact when they feel inclined to be dissatisfied with the degree of financial support accorded their activities, by the Institute. I am sure they would not want to feel that they were promoting their own local interests at the expense of other members unable to enjoy like privileges.

Now of course there are many Section activities which do, directly or indirectly benefit the Institute as a whole. Surely no one will deny the value to the Institute of the splendid work of the Section membership committees, and occasional social activities which assist in obtaining desirable members are, without doubt, of benefit to the Institute as a whole as well as to the individual Sections. No hard and fast rules can be laid down. The important thing is that members fortunate enough to be able to enjoy participation in Section activities might well bear in mind that after all, the principal functions and activities of the Institute must be carried out on a national, or perhaps I should say continental basis, and that in the long run the Section members will benefit most by so planning and conducting their Section affairs *as to contribute to*, as well as enjoy the benefits of these broader activities. They owe this much to that $^1/_3$ of the membership who help to pay their cost without being able to participate in them.

To sum up the whole matter, an insight into the "workings" of the Institute seems to reveal that its aims and activities are rooted in a spirit of mutual helpfulness to each other and disinterested service to humanity. Its officers, its headquarters staff and those who work on its committees all share in that spirit. The principal obligation of membership, it seems, is to cultivate that spirit, the possession of which, after all is said and done, yields the most lasting satisfactions of the professional life.

Resonant Lines in Radio Circuits

Resonant transmission lines may be used as circuit elements in the ultra-short wave range as a means of obtaining high impedance with low loss. The lines may be of either concentric tubes or 2 wires, and are sufficiently small that they may be placed within the apparatus. These circuits can be made highly selective, and when used to control oscillator frequency will give stability comparable to that of a crystal. The mathematical relations governing their operation and several applications are discussed in this paper.

By
FREDERICK EMMONS TERMAN
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AT THE HIGHER frequencies now used in radio communication and, in particular, at frequencies above 30 megacycles it is possible and sometimes highly desirable to replace the usual circuit elements by resonant transmission lines. At these high frequencies the wave length is so small that resonant lines are of reasonable physical dimensions and, when properly built, have low losses and a large circulating voltampere capacity.

The principal uses that thus far have been made of resonant transmission lines are with high frequency oscillators. Engineers of the Radio Corporation of America have used long resonant lines to replace the oscillator tank circuit, and equipment embodying this principle is being used in the telephone system connecting the Hawaiian Islands.[1] Mouromtseff and Noble have designed a water cooled tube in such a way that the grid and plate structures are part of a half wave length resonant line which is used as the tank circuit of the oscillator. With this arrangement it is possible to obtain frequencies about twice as high as can be realized with the same tube in a conventional circuit.[2]

It is the purpose of the present paper to present the fundamental properties of resonant lines when used as substitutes for the circuit elements commonly employed at high frequencies. In particular,

Full text of a paper recommended for publication by the A.I.E.E. committee on communication, and scheduled for discussion at the A.I.E.E. Pacific Coast convention, Salt Lake City, Utah, Sept. 3–7, 1934. Manuscript submitted April 30, 1934; released for publication May 16, 1934. *Not published in pamphlet form.*

1. For all numbered references see list at end of paper.

the possibilities of resonant lines as a means of developing high impedances, highly selective circuits, low loss inductances and capacitances, and high voltage step-up ratios will be investigated, and the best proportions for each purpose determined.

Fundamental Relations

Resonant lines may be either open- or short-circuited at the receiver. The voltage and current distributions that result for these cases are shown in Fig. 1. These curves are discussed in many text-books and so need not be considered in detail here. It is sufficient to call attention to the fact that with an open circuited receiver the voltage is low at points that are an odd number of quarter wave lengths distant from the receiver, and high at points at an even number of quarter wave lengths. For the short-circuited receiver the relations are the opposite; the voltage is low at points of high voltage for the open-circuited receiver, and *vice versa*. The current distribution for the open-circuited receiver is exactly the same as the voltage distribution for the short-circuited receiver; conversely the current distribution for the short-circuited receiver follows the same law as the voltage distribution for the open-circuited receiver. In dealing with resonance phenomena in transmission lines, the receiving end of the line always is chosen as the reference point. This is because the resonances arise as a result of reflections at the receiver and the maxima and minima in the standing wave patterns are hence always an exact multiple of a quarter wave length from the receiver.

The impedance of the line looking toward the receiver follows the voltage distribution in a general way, being high or low depending upon whether the voltage is at a maximum or minimum. The curves of impedance and power factor also are given in Fig. 1. It will be observed that the power factor passes through unity whenever either the voltage or current is at a minimum, but is very nearly 90 deg leading or lagging for other conditions.

The formulas giving the properties of resonant lines are to be found in all books on transmission line theory and are

For open circuit at receiver

$$\begin{aligned} E_s &= E_r \cosh(\alpha + j\beta)\, l \\ I_s &= \frac{E_r}{Z_0}\sinh(\alpha + j\beta)\, l \\ Z_s &= \frac{E_s}{I_s} = \frac{Z_0}{\tanh(\alpha + j\beta)\, l} \end{aligned} \tag{1a}$$

For short circuit at receiver

$$\begin{aligned} E_s &= I_r Z_0 \sinh(\alpha + j\beta)\, l \\ I_s &= I_r \cosh(\alpha + j\beta)\, l \\ Z_s &= \frac{E_s}{I_s} = Z_0 \tanh(\alpha + j\beta)\, l \end{aligned} \tag{1b}$$

where

E_s = sending end voltage
E_r = receiving end voltage
I_s = sending end current
I_r = receiving end current
Z_s = impedance at sending end looking toward receiver
Z_0 = characteristic impedance of line
$\alpha + j\beta$ = propagation constant of line
l = line length

At high frequencies, such as are of interest here, the propagation constant $(\alpha + j\beta)$ takes the following simplified form:[3]

$$\alpha + j\beta = \frac{R}{2Z_0} + \frac{GZ_0}{2} + j\frac{2\pi}{\lambda} \tag{2}$$

where

R = resistance in ohms per unit length
Z_0 = characteristic impedance in ohms
G = leakage conductance in mhos per unit length
λ = length corresponding to one wave length

At radio frequencies the characteristic impedance is almost exactly a pure resistance having a value $Z_o = \sqrt{L/C}$, and the wave length with air insulation corresponds extremely closely to the wave length calculated on the basis of the velocity of light, *i. e.*, λ = (velocity of light)/frequency.

As a result of the fact that the characteristic impedance is real, the only imaginary term in the right-hand side of eq 2 is the last term, so that

$$\beta = \frac{2\pi}{\lambda} = \frac{2\pi f}{c} \tag{3}$$

where c is the velocity of light and f is the frequency. Likewise, if the leakage conductance is assumed to be zero, which is always the case in well constructed radio frequency transmission lines, the attenuation constant α is given by the first term on the right-hand side of eq 2 and so becomes

$$\alpha = \frac{R}{2Z_0} \tag{4}$$

The characteristic impedance Z_0 for concentric tube and 2-wire transmission lines is readily calculated by the usual formulas:

$$\left.\begin{array}{l}\text{Characteristic impedance for}\\ \text{concentric tube line}\end{array}\right\} = 138 \log_{10}\frac{b}{a} \tag{5a}$$

$$\left.\begin{array}{l}\text{Characteristic impedance for}\\ \text{2-wire line}\end{array}\right\} = 276 \log_{10}\frac{b}{a} \tag{5b}$$

where

b = inner radius of outer conductor in concentric tube line or the spacing between wire centers with a 2-wire line
a = outer radius of inner conductor in a concentric tube line, or the conductor radius in a 2-wire line

The resistance R that appears in eqs 2 and 4 can be readily calculated at radio frequencies for the usual types of lines because the skin effect is so great at these frequencies that the skin depth is very small. In general, when the skin depth is small compared with the radius of curvature of the conductor surface, the resistance of the conductor is equal to the resistance of a surface layer having a depth which for copper is $6.62/\sqrt{f}$ cm. With a concentric tube transmission line this results in a resistance per unit line given by the following formula

$$R = 41.6\sqrt{f}\left(\frac{1}{a} + \frac{1}{b}\right) \times 10^{-9} \text{ ohms per cm} \tag{6}$$

where

b = inner radius of outer conductor in centimeters
a = outer radius of inner conductor in centimeters
f = frequency in cycles

In the case of a 2-wire transmission line with large conductor spacing, the resistance, taking into ac-

count skin effect, is twice the resistance of a single wire considered as an isolated conductor and so becomes

$$R = 83.2\frac{\sqrt{f}}{a} \times 10^{-9} \text{ ohms per cm} \qquad (7)$$

The notation is the same as in eq 5 except that a is now the radius of the conductor, in centimeters. When the 2 wires are reasonably close together, the actual resistance is somewhat higher than given by eq 7 because of the proximity effect which results in each of the wires inducing eddy currents in the other wire. The proximity factor can be taken into account by multiplying the resistance calculated from eq 7 by the factor given in Fig. 2.[4]

All of the fundamental factors required to obtain an analysis of the properties of resonant transmission lines at high frequencies now have been considered. Equations 1a and 1b give the voltage, current, and impedance relations existing on the line in terms of the line length, frequency, and line constants. Equations 3 and 4 give the wave length constant and the attenuation factor while eqs 6 and 7 give the resistance of the line at high frequencies. These fundamentals now will be applied to the solution of various problems involving resonant transmission lines.

Resonant Transmission Lines as High Impedance Devices

Resonant transmission lines can be used as interstage coupling devices for vacuum tube amplifiers

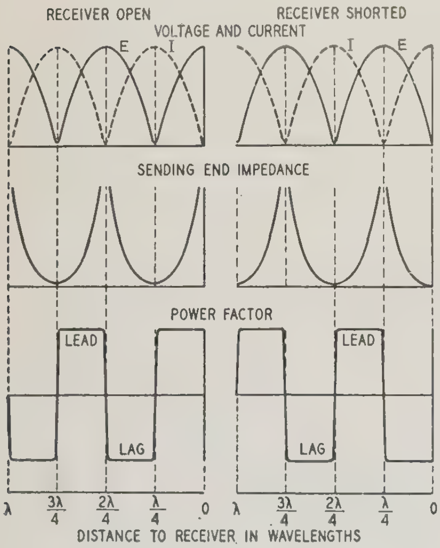


Fig. 1. Voltage, current, sending end impedance, and sending end power factor of resonant transmission lines as functions of distance from receiver

in place of the parallel resonant circuit normally employed. At high frequencies resonant lines have the advantage of giving greater impedance and greater selectivity than are obtainable with a parallel tuned circuit, and appear to have real possibilities in the receiver art.

A resonant transmission line developing a high impedance may consist either of a line an odd number of quarter wave lengths long and short-circuited at the receiver or an even number of quarter wave lengths long and open-circuited at the receiver, as is apparent from Fig. 1. In Appendix I it is shown that by a manipulation of eqs 1 and 2 the sending end impedance for both cases is

$$Z_s = \frac{8Z_0^2 f}{Rnc} \qquad (8)$$

where

Z_s = sending end impedance of the line
Z_0 = characteristic impedance of the line
f = frequency
R = line resistance per unit length
n = number of quarter wave lengths in the line
c = velocity of light

This is the general expression for the sending end impedance when the line is of such a length as to give a high impedance.

In the particular case of a concentric tube line it is advantageous to rearrange eq 8 by making use of eqs 5a and 6. As shown in Appendix I this gives

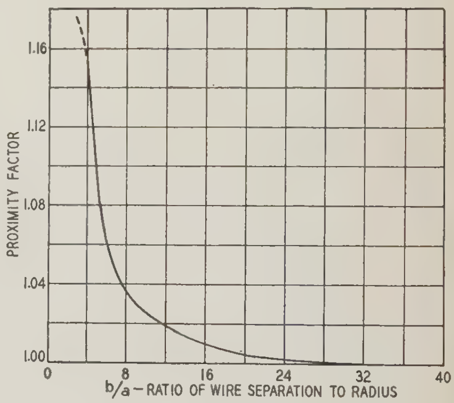
$$Z_s = \frac{122.2\sqrt{f}\,b}{n}\left[\frac{(\log_{10} b/a)^2}{1 + b/a}\right] \qquad (9)$$

where

b = inner radius of outer conductor in cm
a = outer radius of inner conductor in cm

Examination of this equation yields some very interesting and important results. In the first place,

Fig. 2. Proximity effect factor for 2-wire line with wires spaced closely



it may be noted that the sending end impedance obtainable is inversely proportional to the number of quarter wave lengths involved in the line, is directly proportional to the diameter of the outer conductor, is proportional to $\sqrt{f}$, and is a function of the line proportions (b/a). For any given outer diameter there is a best diameter for the inner conductor. This best proportion is $b/a = 9.2$, but is not particularly critical with respect to line proportions as can be seen from Fig. 3. One now may rewrite eq 8 in a very convenient form:

$$Z_s = \frac{11.11\sqrt{f}\,b}{n} F \qquad (9a)$$

where F is the factor given by Fig. 3, and with optimum line proportions will be equal to 1.

Substituting reasonable numerical values in eq 9a shows that extremely high impedances are readily obtainable at high frequencies. Thus for $b = 1$ cm, $f = 60 \times 10^6$ cycles, $n = 1$, and $F = 1$ (optimum proportions), it is found that $Z_s = 86{,}000$. It may

be noted that this line is so small that it can be coiled up and used in a radio receiver or portable transmitter. If the line diameter is enlarged to 10 cm, the sending impedance is 860,000 ohms, a truly enormous impedance at a frequency of 60×10^6 cycles per second.

Equation 8 indicates that the sending end impedance increases proportionally to $\sqrt{f}$. This behavior is the opposite of that of ordinary circuits and is correspondingly important. It comes about because, although the resistance per unit length increases with frequency, the increase is proportional to $\sqrt{f}$, whereas the length of the conductor involved is inversely proportional to frequency.

A 2-wire transmission line exhibits exactly the same type of behavior as the concentric tube line although the formula differs slightly. It is shown in Appendix I that for this case

$$Z_s = \frac{23.95\sqrt{f}\,b}{n}G \tag{9b}$$

where G is a factor given in Fig. 3, and b is the wire spacing in centimeters. The optimum proportions here are $b/a = 8.0$, but are not critical.

The impedance possibilities of resonant lines at frequencies such as 10 megacycles and higher can be summarized as follows: An impedance in the order of 100,000 ohms or more is readily obtainable with reasonable proportions. The sending end impedance obtainable is greater the higher the frequency and is also directly proportional to the outside dimension of the line. The highest impedance is obtained when the line is a quarter wave length long short-circuited at the receiver, and for highest impedance there is an optimum proportion.

High Impedance Resonant Lines as Selective Circuits

The selectivity of a high impedance such as obtained by a quarter wave length resonant line can be thought of as a measure of the extent to which the impedance varies with frequency in the region around exact resonance. This variation of impedance with frequency is a property more or less independent of the magnitude of the impedance obtained and so must be considered separately. In particular, the conditions that give maximum selectivity are not the same as those that give maximum impedance.

It is shown in Appendix II that as frequency is varied slightly about resonance the impedance of a line varies according to exactly the same law as does the impedance of an ordinary parallel resonant circuit. The selectivity around the resonant frequency is hence expressible in terms of an equivalent selectivity factor, Q, just as is the selectivity of ordinary resonant circuits.[5] The value of Q that results is derived in Appendix II, and is

$$Q = \frac{2\pi Z_0 f}{Rc} \tag{10}$$

In the particular case of concentric lines the formula may be made more usable by substituting for Z_0 and R from eqs 5 and 6. This yields

$$Q = 0.694\sqrt{f}\,b\left(\frac{\log_{10} b/a}{1 + b/a}\right) \tag{11}$$

$$= 0.0839\sqrt{f}\,b\,H \tag{11a}$$

where the notation is the same as previously used with concentric lines with the addition that H is a factor given in Fig. 4. As may be seen, Q is proportional to $\sqrt{f}$, is proportional to the diameter b of the outer conductor, is a function of the line proportions (b/a), and is independent of the number of quarter wave lengths involved in the line. It is particularly interesting to note that, unlike ordinary circuits, the selectivity factor, Q, tends to become larger the greater the frequency.

The value of Q will be greatest when the line proportions make Z_0/R in eq 10 a maximum. Inspection of eq 4 shows that this is also the requirement for minimum attenuation factor, α, which already is known to occur when $b/a = 3.6$ for concentric lines.[6]

A 2-wire line exhibits exactly the same selectivity characteristics as a concentric tube line, although the numerical coefficients differ. It is shown in Appendix II that the equation for the 2-wire line corresponding to eq 11a is

$$Q = 0.0887\sqrt{f}\,bJ \tag{12}$$

where J is a factor given in Fig. 4. The line proportions are optimum when $b/a = 2.72$ if the prox-

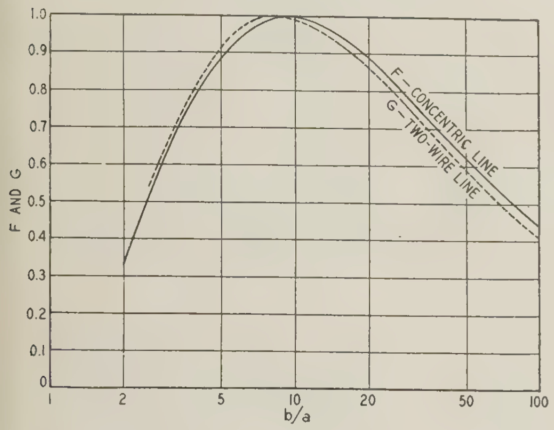


Fig. 3 (left). Factors F and G as functions of b/a, giving the relative impedance of a resonant line

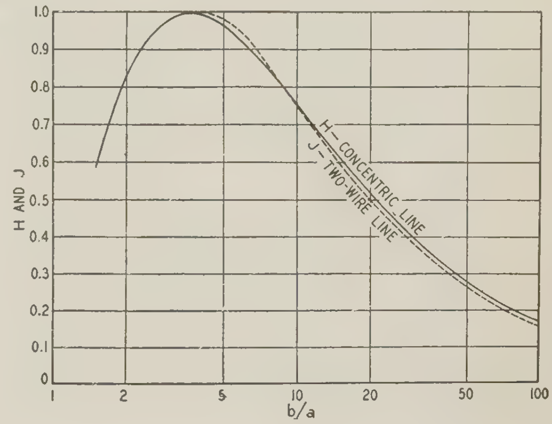


Fig. 4 (right). Factors H and J as functions of b/a, giving the relative selectivity factor of a resonant line

imity effect is neglected, or when the ratio is between 3 and 4 if the proximity effect is included.

Substitution of reasonable numerical values in eqs 11 and 12 shows that the value of Q obtainable with resonant lines is surprisingly large at frequencies in the short wave and ultra-short wave range. For example, a quarter wave length concentric line 1 cm in outer diameter, of optimum proportions, and operating at 60 megacycles, has an equivalent selectivity factor, Q, of 650, and if the diameter is increased to 10 cm Q becomes 6,500. These values are much higher than can be obtained with ordinary resonant circuits, and are comparable to or exceed the effective selectivity of quartz crystal vibrators. It thus appears that resonant lines are as effective as a quartz crystal for stabilizing the frequency of a short wave oscillator.

In ordinary parallel resonant circuits the resonant impedance can be expressed as $Q\omega L$, where ωL is the reactance of the inductive branch of the circuit and Q is the ratio of ωL to the circuit resistance. An analogous expression can be obtained for a resonant transmission line by combining eqs 8 and 10 with the interesting and useful result

$$Z_s = \left(\frac{4Z_0}{\pi n}\right) Q \tag{13}$$

In summarizing the selectivity properties of resonant lines the most noteworthy points to consider are the differences in requirements for maximum selectivity as against maximum impedance. In general the best proportions are distinctly different, a lower characteristic impedance being preferable for maximum selectivity. The selectivity is also independent of the number of quarter wave lengths involved in the line whereas the impedance is inversely proportional to the number of quarter wave lengths. However, the selectivity and impedance both vary with frequency and dimension b in the same way.

Resonant Lines as Voltage Step-Up Devices

An important use of an ordinary resonant circuit is as a voltage step-up device employing the well-known resonance rise of voltage existing in a series circuit. A transmission line can be used for the same purpose. The idea is to use an open-circuited receiver and a line an odd number of quarter wave lengths long, in which case the resonance rise of voltage is from the sending end to the receiving end, or else to employ a short-circuited receiver and a line that is an even number of quarter wave lengths long, in which case the resonant rise of voltage is from the sending end to a point an odd quarter of a wave length from the sending end.

The voltage step-up properties of such lines can be determined by making use of the fundamental equations of the line, and reducing them to a form that will permit ready interpretation for this special case. This is done in Appendix III and yields the following result:

$$\text{Ratio of voltage step-up} = \frac{8Z_0 f}{Rnc} \tag{14}$$

Likewise it is shown in the same appendix that the voltage step-up ratio in the vicinity of resonance has exactly the same type of selectivity characteristic as the voltage step-up in an ordinary resonant circuit, so that the voltage rise effect may be said to have an effective selectivity factor that can be expressed by the following equation

$$Q = \frac{2\pi Z_0 f}{Rc} \tag{15}$$

It may be observed that Q is exactly the same here as for the same line when used as a high impedance device. A comparison of eqs 14 and 15 shows that the step-up obtainable is $(4/\pi n)Q$. It should be noted that the step-up ratio is greatest when the line is only a quarter wave length long and is not Q as in a simple series circuit. Inasmuch as the selectivity of resonant lines can be made high, the voltage step-up obtainable is correspondingly large and, unlike ordinary circuits, tends to increase as the frequency is increased.

Resonant Lines as Low Loss Reactances

When a line that is either open- or short-circuited at the receiver is not an exact multiple of a quarter wave length long the sending end impedance is primarily reactive with a low power factor. The impedance is inductive in a short-circuited receiver when the line is shorter than an odd number of quarter wave lengths and longer than an even number. With an open-circuited receiver an inductive reactance is obtained with the line longer than an odd number of quarter wave lengths, and shorter than an even number. This is shown in Fig. 1. The important practical case is for inductive rather than capacitive reactance, because low loss capacitive reactances can be obtained readily by conventional methods, whereas low loss inductive reactances are difficult to achieve at high frequencies. The inductive case is also important because in a circuit where a resonant line is used to develop a high impedance in association with a vacuum tube, the tube electrode capacitance requires that the line have an inductive reactance in order that the combination of line and tube may give resonance.

The nature of the reactances obtainable can be ascertained by rearranging the general equation for sending end impedance and neglecting terms that are important only at or very near resonance. This has been done in Appendix IV and gives:

For a short-circuited receiver:

$$Z_s = \frac{Rc\dfrac{l}{\lambda}}{2f\cos^2 2\pi\left(\dfrac{l}{\lambda}\right)} + jZ_0\tan\left(2\pi\frac{l}{\lambda}\right) \tag{16a}$$

For an open-circuited receiver:

$$Z_s = \frac{Rc\dfrac{l}{\lambda}}{2f\sin^2 2\pi\left(\dfrac{l}{\lambda}\right)} - j\frac{Z_0}{\tan\left(2\pi\dfrac{l}{\lambda}\right)} \tag{16b}$$

The notation is the same that already has been used with the addition that (l/λ) is the line length measured in wave lengths. The equation does not hold of course when (l/λ) approaches an integral multiple

of a quarter wave length. It may be noted that the reactive component of the impedance is proportional to the characteristic impedance Z_0, and varies cyclically with line length. The reactance can be controlled either by varying Z_0 or the length, and may be varied from perhaps $^1/_{10}$ to 10 times the characteristic impedance.

The ratio of reactance to resistance components of the sending end impedance can be called the selectivity factor of the reactance, and for both terminations is

$$Q = \frac{Z_0 f}{Rc} \frac{\sin\left(4\pi \frac{l}{\lambda}\right)}{\frac{l}{\lambda}} \tag{17}$$

Comparison of eqs 10 and 17 shows that Q varies with line proportions and frequency according to the same law for both the impedance of the resonant line and the reactance of the line when not in resonance. The value of Q now varies cyclically with length, however, with a general lower trend as length increases. This is shown in Fig. 5, which gives values of Q for the reactance of a line not in resonance divided by values of Q for a resonant line of the same construction, and at the same frequency. It is apparent that the "Q" of the reactance compares favorably with that of resonant lines. Also, the lowest loss inductive reactance is obtained when a short-circuited line less than a quarter wave length long is used, and the lowest loss capacitive reactance when an open line less than a quarter wave length long is used. Longer lines than these can be arranged to give the same reactance, but will have greater losses.

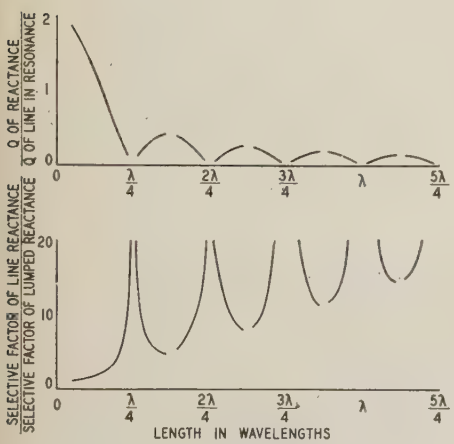


Fig. 5. Effect of line length on selective characteristics of reactances of lines

The reactances obtained from lines can be used in the same way as those of ordinary coils and condensers, and as far as everything except selectivity is concerned the equations and laws for lumped circuits hold without change. When lumped coils and condensers are associated with the line, it is necessary to include the losses in these elements in the calculations; and these extra losses are commonly more than the line losses unless unusual precautions are taken. In particular, when a line is combined with the tube capacitance to give resonance, the losses in the tube leads will dominate the situation unless the tube is properly constructed.

Improved Selectivity Characteristics

The selectivity characteristics of circuits involving reactances derived from lines are not the same as when ordinary lumped reactances are used, however. This is because the reactance obtained from lines varies more rapidly with frequency than does the reactance of an ordinary condenser or coil. *As a result, a reactance having a certain magnitude and "Q" has greater effective selectivity than does a lumped reactance having the same magnitude and "Q".* The magnitude of this effect is computed in Appendix V, and is

$$\frac{\text{Selective factor of line reactance}}{\text{Selective factor of lumped reactance}} = \frac{4\pi \frac{l}{\lambda}}{\sin\left(4\pi \frac{l}{\lambda}\right)} \tag{18}$$

If the line length is very small this factor becomes unity as might be expected, but otherwise the factor is greater than unity and tends to become very great when the line is long. Equation 18 is plotted in Fig. 5.

The use of eq 18 can be illustrated by a specific example. Assume $l/\lambda = 0.2$; then the factor is 4.25. If the line reactance now is tuned to resonance by a lossless condenser the effective selectivity factor of the circuit will be $(4.25 + 1)/2 = 2.62$ times as great as it would be if the line were replaced by a coil having the same ratio of reactance to resistance.

The real merit of a line reactance from the point of view of selectivity is the ratio of rate of change of reactance to the effective resistance. This can be shown to vary cyclically, repeating every even multiple of a quarter wave length. Thus a line 0.7 wave length long has as good selectivity characteristics as a reactance obtained from a line of 0.2 wave length, although in the latter Q as given from eq 17 is greater and the resonant impedance and resonant step-up effects likewise are greater.

Suggested Applications

It has been demonstrated that resonant lines can be used to replace ordinary circuit elements and tuned circuits, and that the performance of resonant lines at the higher frequencies used in radio communication is vastly superior to that of any ordinary type of circuit or circuit element. At wave lengths in the order of 10 m it is a simple matter to obtain resonant impedance in excess of 100,000 ohms and to obtain resonant impedances, resonant step-up effects, and either inductive or capacitive reactances that have an effective circuit selectivity factor Q ranging from 500 to perhaps 5,000. Unlike ordinary circuit elements, the resonant lines perform better the higher the frequency. The full possibilities of resonant lines can be obtained only when they are designed properly. There is a best proportion that gives the highest values of Q, and there is also a different proportion that gives the highest impedance.

Possible applications of resonant lines to ultra-

short wave radio technique appear to be almost without limit, since at these high frequencies resonant lines can out-perform any circuit employing lumped elements, and at the same time are so compact as to be usable even in small receivers by the expedient of using a coiled concentric line.

A few of the possible applications that immediately suggest themselves are shown in Fig. 6. In

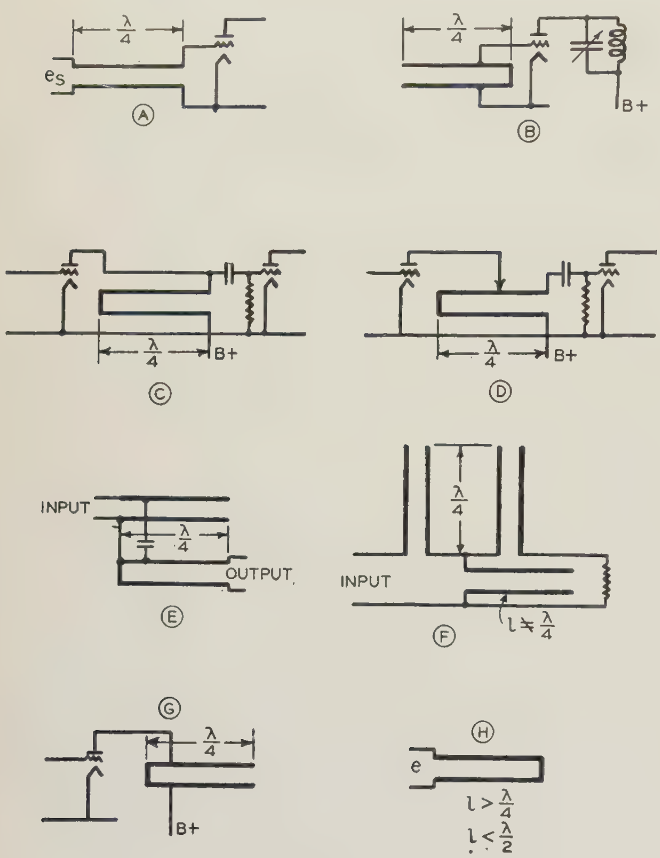


Fig. 6. Applications for resonant lines

A. Line as step-up circuit
B. Line as oscillator frequency control
C and D. Line as interstage coupling device
E and F. Line as band pass filter
G. Line as power amplifier tank circuit
H. Line as condenser that will pass direct current

the case of the oscillator frequency control arrangement (*b*) it is possible, by coupling the oscillator near the shorted end of the line so that only a small effect is reflected into the resonant line, to obtain frequency stability comparable to or better than that given by a crystal. Temperature effects can be made practically nil by using a construction and mounting such that the line length cannot change with temperature. At (e) in Fig. 6 are shown 2 resonant lines loosely coupled together to serve as a band pass filter such as commonly is used in radio receivers; and at (f) is shown a simple band pass filter of the type commonly used in telephone carrier work, with the 2 quarter wave lines acting as series resonant circuits, and the shunt line serving as a capacitance or inductance as desired. At (h) is indicated a line arranged to function as a capacitive reactance and *yet pass direct current,* a common need in many tube circuits.

Appendix I—Derivation of Equations for Impedance of Resonant Lines

For an open-circuited receiver the sending end impedance is

$$Z_s = \frac{Z_0}{\tanh(\alpha l + j\beta l)} \tag{19}$$

But βl is an exact multiple of π, so that this can be rewritten as

$$Z_s = \frac{Z_0}{\tanh \alpha l} \tag{20}$$

For the short-circuited case the sending end impedance is

$$Z_s = Z_0 \tanh(\alpha l + j\beta l) \tag{19a}$$

However, here βl is an odd multiple of $\pi/2$, so eq 19a can be written as

$$Z_s = \frac{Z_0}{\tanh \alpha l} \tag{20a}$$

This is the same as eq 20, so the 2 cases can be treated alike from now on.

Now αl is always small because of the low line losses, so that for all practical purposes $\tanh \alpha l = \alpha l$. Equation 20 hence becomes:

$$Z_s = \frac{Z_0}{\alpha l}$$

By making use of eq 4, and taking advantage of the fact that l is an exact multiple of a quarter wave length, one has

$$Z_s = \frac{Z_0}{\alpha l} = \frac{2Z_0^2}{Rl} = \frac{8Z_0^2}{Rn\lambda} = \frac{8Z_0^2 f}{Rnc} \tag{21}$$

This is the same as eq 8.

Equation 9 is obtained by substituting in eq 21 the value of R given by eq 6 and the expression for Z_0 from eq 5a. The right-hand side of eq 9 is maximum when $b/a = 9.2$, and eq 9a represents eq 9 for this optimum b/a multiplied by the factor F, which is the ratio of the impedance with the actual b/a to the impedance with optimum b/a.

Equation 10 is obtained from eq 8 in the same way that eqs 9 and 9a are, except that the expressions for R and for Z_0 now are given by eqs 7 and 5b, respectively, and the resistance must be multiplied by the proximity factor given in Fig. 2. The resulting equation becomes

$$Z_s = \frac{244.4\sqrt{f}\,b}{n}\left[\frac{\log b/a^2}{\frac{b}{a}P}\right] \tag{22}$$

where P is the proximity factor and is a function of b/a. The right-hand side is a maximum when $b/a = 8.0$, and eq 10 merely represents the impedance with this optimum b/a multiplied by the factor G which is the ratio of the impedance for any desired b/a to the impedance with the optimum b/a, b being constant.

Appendix II—Selectivity Equations for Resonant Lines

The selectivity of resonant lines is determined by the variation of impedance as the frequency is varied about resonance. Consider, for example, eqs. 1a and 1b. These can be written

$$Z_s = \frac{Z_0}{\tanh(\alpha l + j\beta l)} = \frac{Z_0}{\tanh(\alpha l + j2\pi fl/c)}$$

and (23)

$$Z_s = Z_0 \tanh(\alpha l + j\beta l) = Z_0 \tanh(\alpha l + j2\pi fl/c)$$

If f and l are such that the line is in exact resonance, then βl is an exact multiple of $\pi/2$ and both equations become $Z_s = Z_0/\tanh \alpha l$. Assume now that the frequency is off resonance by an amount δf. In this case

$$\beta l = \frac{n\pi}{2} + j2\pi l\delta f/c$$

or

$$Z_s = \frac{Z_0}{\tanh\left(\alpha l + j\frac{2\pi l}{c}\delta f\right)} \tag{24}$$

But as δf and αl are small, one can write

$$Z_s = \frac{Z_0}{\alpha l + j\frac{2\pi l}{c}\delta f} \tag{25}$$

This expression for impedance is of exactly the same form as the impedance of an ordinary parallel circuit about resonance. Thus the usual rule for determining Q may be applied, which is that when δf is such that the real and imaginary terms of the denominator are equal,

$$\delta f = \frac{\text{Resonant frequency}}{2Q}$$

Hence

$$Q = \frac{f}{2\delta f} = \frac{f}{2\alpha l/(2\pi l/c)} = \frac{\pi f}{\alpha c} \tag{26}$$

Substituting from eq 4 for α gives

$$Q = \frac{2\pi f Z_0}{Rc} \tag{27}$$

For a concentric line eq 27 can be simplified by introducing eqs 6 and 5a for R and Z_0, respectively, with the result given in eq 11. The line proportion that makes Q in eq 11 maximum is $b/a = 3.6$, and eq 11a merely gives the Q for this optimum proportion multiplied by the factor H which is the ratio of Q for any value of b/a to the Q for optimum b/a.

For a 2-wire line eq 27 can be simplified by following the same procedure as for the concentric tube. Here the optimum proportions are for b/a between 3 and 4. Equation 12 is the result, where J is the factor corresponding to H, but on the assumption that the reference condition is $b/a = 4$.

Appendix III—Voltage Step-Up Equations of Resonant Lines

When the receiver is open and the line is an odd number of quarter wave lengths long (n odd):

$$\frac{E_s}{E_r} = \cosh(\alpha l + j\beta l) = \cosh\left(\alpha l + jn\frac{\pi}{2}\right) \tag{28}$$

$$= j\sinh \alpha l$$

since αl is small we have

$$\text{Step-up ratio} = \left|\frac{E_r}{E_s}\right| = \frac{1}{\alpha l}$$
$$= \frac{8Z_0 f}{Rnc} \tag{29}$$

If the receiver is short-circuited, $E_s = I_r Z_0 \sinh\ (\alpha l + j\beta l)$ and the voltage at a voltage loop is $I_r Z_0 \sinh\left[\alpha l + j\beta l - \frac{\pi}{2}\right) = -jI_r Z_0 \cosh (\alpha l + j\beta l)$

$$\text{Step-up ratio} = \frac{\cosh \alpha l}{\sinh \alpha l} = \frac{1}{\alpha l} = \frac{8Z_0 f}{Rnc} \tag{30}$$

The effective Q can be determined for this case as was done in Appendix II. We note in both open- and short-circuited receivers that as the frequency is brought off resonance by an amount δf the result is the same as in eq 25, and Q, hence, follows the same law for voltage step up as for lines operated to give high impedance.

Appendix IV—Equations for Reactance Developed by Lines

For short-circuited receiver eq 1 gives

$$Z_s = Z_0 \tanh(\alpha l + j\beta l) = Z_0 \frac{\sinh 2\alpha l + j\sin 2\beta l}{\cosh 2\alpha l + \cos 2\beta l} \tag{31}$$

but as αl is small, $\cosh 2\alpha l = l$, and $\sinh 2\alpha l = 2\alpha l$. Hence

$$Z_s = Z_0 \frac{2\alpha l + j\sin 2\beta l}{1 + \cos 2\beta l} = Z_0\left[\frac{\alpha l}{\cos^2 \beta l} + j\tan \beta l\right]$$
$$= \frac{Rc\left(\frac{l}{\lambda}\right)}{2f\cos^2 2\pi\left(\frac{l}{\lambda}\right)} + jZ_0 \tan\left(2\pi\frac{l}{\lambda}\right) \tag{32}$$

In the case of an open circuit at the receiver the derivation follows the same steps, but starts with the general equation of sending end impedance for an open receiver.

Appendix V—Selectivity Characteristics of Reactances Developed by Resonant Lines

In the case of ordinary reactances the change of reactance Δx produced by a fraction change of frequency $\Delta f/f$ is

$$\Delta x = X\frac{\Delta f}{f} \tag{33}$$

In the case of lines this simple relation no longer holds. Thus for the short-circuited receiver case of eq 16a

$$X = Z_0 \tan 2\pi\left(\frac{l}{\lambda}\right) = Z_0 \tan\left(\frac{2\pi f l}{c}\right) \tag{34}$$

$$\frac{dx}{df} = Z_0 \frac{2\pi\, l/c}{\cos^2 2\pi f l/c} = \frac{Z_0\left(2\pi\frac{l}{\lambda}\right)}{f\cos^2 2\pi\left(\frac{l}{\lambda}\right)} \tag{35}$$

Hence

$$dx = \frac{2\pi l/\lambda}{\cos^2(2\pi l/\lambda)} Z_0 \frac{\delta f}{f} \tag{36}$$

Multiplying both numerator and denominator by $\tan\left(2\pi\frac{l}{\lambda}\right)$ and reducing gives

$$dx = \frac{4\pi\frac{l}{\lambda}}{\sin\left(4\pi\frac{l}{\lambda}\right)} X \tag{37}$$

Comparison of eqs 33 and 37 immediately yields eq 18. The same result also will be obtained when this same procedure is applied to eq 16b.

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Electron Emission

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Edison's observation of the discharge of negative electricity from the carbon filament of an incandescent lamp to an auxiliary electrode in the bulb, commonly known as the "Edison effect," remained unexplained until the beginning of the 20th century. Since that time, an entire new industry—radio—has grown up as a result of continued research in the emission of electrons from hot cathodes. This article, seventh of a series prepared under the sponsorship of the A.I.E.E. committee on education, reviews some of the more important observations and conclusions obtained from investigations in this field.

THE OBSERVATION made by Edison on the discharge of negative electricity from the carbon filament of an incandescent lamp to an auxiliary anode in the bulb (Edison effect) remained unexplained until O. W. Richardson started his investigations at the beginning of this century. While Richardson and other English investigators used metals (such as platinum and sodium) and carbon as emitters, A. Wehnelt showed (in 1905) that metallic oxides, such as those of barium (BaO), calcium (CaO), and strontium (SrO), also emit electrons at high temperatures, and Jentzsch (1908) made similar observations on the oxides of a great many elements. Between these dates and 1913 several workers in this field reached the conclusion that the observed emission is caused in all cases, by chemical effects of residual traces of gases, and that under better vacuum conditions the emission phenomenon would disappear. Furthermore, there appeared to be some valid experimental evidence for this point of view. However, with the publication (1913–14) by I. Langmuir of the results of his investigations on the electron emission from tungsten in high vacuum and his evidence of space charge effects under these conditions, the subject of thermionics entered a new stage of development of extreme importance both theoretically and practically.

The past 2 decades have seen a veritable revolution in many industrial operations, produced by the application of electronic devices of the most varied types. A whole new industry—that of radio—has grown up as a result of the investigations on the emission of electrons from hot cathodes and on the various methods by which these electrons may be controlled.

Equations for Electron Emission

In his 1903 paper, Richardson developed an equation expressing the variation in electron emission with temperature. Assuming that at any temperature only those electrons are able to escape through the surface that have an energy in excess of a certain critical value, E, and, furthermore, assuming that the distribution of kinetic energies of the electrons in the metal is of the Maxwell Boltzmann type, Richardson derived the following emission equation:

$$N = n\sqrt{\frac{kT}{2\pi m}}\,\epsilon^{-E/kT} \tag{1a}$$

where

N = number of electrons per unit area per unit time
n = number of electrons per unit volume in the metal
k = Boltzmann gas constant = 1.371×10^{-16} ergs per degree
T = absolute temperature on Centigrade scale (degrees K)
m = mass of an electron = 9.0×10^{-28} g
ϵ = base of natural system of logarithms

Since n is assumed to be a constant for any metal, independent of T, eq 1 may be written in the form

$$I = a\sqrt{T}\,\epsilon^{-b/T} \tag{1b}$$

where I is the electron current per unit area, and a and b are *constants* for any given emitting surface. This is the form in which Richardson's equation usually is stated. It should be observed that the constant b corresponds to E/k in eq 1a. Now E can be expressed in terms of the voltage drop, ϕ, through which an electron would have to be accelerated in order to acquire the kinetic energy, E, by the relation

$$E = bk = \phi e$$

where

e = electric charge on an electron
= 4.770×10^{-10} electrostatic units (e.s.u.)
= 1.591×10^{-19} coulombs

Hence

$$\phi = \left(\frac{k}{e}\right) b$$

$$= \left(\frac{1.371 \times 10^{-16} \times 300}{4.770 \times 10^{-10}}\right) b \text{ (volts)}$$

$$= 8.62 \times 10^{-5}\, b \text{ (volts)}$$

where the factor 300 is used to convert to the customary volts and b evidently is expressed in degrees K. The quantity ϕ, expressed in volts, is known as the "work function" for electron emission.

While Richardson had pointed out that an equation of the form

$$I = AT^2\,\epsilon^{-b_0/T} \tag{2a}$$

would be just as valid theoretically and would be in satisfactory agreement with observed data, it was shown subsequently by M. v. Laue (1918) and by the author (1922) independently that on the basis of the third law of thermodynamics and Planck's theory of energy quanta, an equation of the latter type must apply, in which A is a universal constant defined by the relation

$$A = \frac{2\pi emk^2}{h^3} \tag{3}$$

where

h = Planck's constant = 6.547×10^{-27} erg sec

e, m, k have the same significance as in the previous equations

The numerical value of the constant is

$A = 60.2$ amp/cm² deg²

More recently, it has been shown that this value of A ought to be multiplied by the factor 2 to take into account the fact, deduced from observations on atomic spectra, that the electron possesses a spin momentum. However, the actual emission data for certain special surfaces are in much better agreement, as is mentioned later, with the value 60.2 than with this theoretical value 120.4.

Equations 1b and 2a may be written in a form that is much more convenient for the actual calculation of the constants a and b or A and b_0. From these equations, it follows that in terms of ordinary logarithms

$$\log I - \frac{1}{2}\log T = \log a - \frac{b}{2.303T} \tag{1c}$$

and

$$\log I - 2\log T = \log A - \frac{b_0}{2.303T} \tag{2b}$$

Thus if $\log (I/\sqrt{T})$ or $\log (I/T^2)$ is plotted against $1/T$, the value of b or b_0 is determined from the slope of the straight line thus obtained, while that of a or A is determined from the intercept on the ordinate axis for $1/T = 0$.

As an illustration of the method of applying eq 1c and 2b, Table I gives emission data actually obtained for a pure tungsten filament under excellent vacuum conditions. From a plot of these data, the following values of the emission constants were derived:

Table I—Emission Data for a Pure Tungsten Filament in a Vacuum

T	$10^3/T$	$\log I + 8$	$\log(I/T^2) + 14$	b_0
1477	0.6770	0.6065	0.2677	52,760
1543	0.6482	1.3432	0.9666	52,620
1640	0.6098	2.2850	1.8554	52,570
1761	0.5679	3.3158	2.8248	52,520
1897	0.5271	4.2696	3.7434	52,690
2065	0.4842	5.3043	4.6743	52,790
2239	0.4467	6.2659	5.5659	52,640
				Avg 52,660

$A = 55.6$ amp/cm² deg²

$b_0 = 52{,}570$ degrees

The last column in Table I gives values of b_0 calculated for each temperature by assuming $A = 60.2$ amp/cm² deg².

It is of interest to point out in this connection that on the basis of the new electron theory of conduction developed by A. Sommerfeld (1928) an equation for electron emission is derived identical with eq 2a with the modified value $2A$ as mentioned already. However, from actual emission data it has been found that: (1) in no case is the observed value of the constant in agreement with this theoretically derived value; (2) for several pure metals, A has a value approximately equal to 60.2; and (3) for composite surfaces, such as thoriated tungsten and oxide coated cathodes, the observed values of A differ considerably even in order of magnitude from the theoretical value. It has been suggested, therefore, that this difference might be ascribed to the existence of a reflection coefficient, r, for the electrons. This would lead to a constant of the form $2A(1 - r)$ in which $r = 0.5$. In a recent paper, J. A. Becker and W. H. Brattain have pointed out that the value of r is probably very small; they suggest that the discrepancy is attributable to the existence of a temperature coefficient for the work function. Thus further investigation still is required to determine the reasons for the fact that factor A as observed from emission data is different from the theoretical value $2A = 120.4$ amp/cm² deg².

Requirements for Accurate Emission Data

During the first decade of the investigations by Richardson, Wehnelt, and others on thermionic emission, considerable doubt was expressed by several other investigators regarding the existence of this phenomenon in such a good vacuum that the effect could not be ascribed to traces of residual gases. This theory that electron emission results from chemical reactions between the metal and residual gases was held very widely, and it was only the epoch-making investigations of Langmuir that finally led to indisputable evidence for the existence of a thermionic emission *per ipse*. In this work, Langmuir developed a technique of producing and maintaining an extremely good vacuum (of the order of 10^{-9} atmosphere) and also demonstrated that if care were taken to obtain a *clean* surface, absolutely reproducible emission data were obtained which could be represented satisfactorily by Richardson's equation. In the case of tungsten, which has an extremely high melting point (3,655 deg K) and a very low rate of evaporation even at 2,400 deg K, ideal experimental conditions could be obtained both as regards extremely low pressures and clean surfaces.

Under these conditions, Langmuir found (1913) that the electron current passing from a filamentary cathode to an adjacent anode (which, of course, was heated to a high temperature in a vacuum, in order to remove occluded gases and oxides) is limited by either of 2 factors: (a) voltage on the anode, or (b) temperature of the cathode. With the cathode at a definite and constant temperature, the electron current to the anode increases at first as the voltage is increased according to the "three halves power law," that is

$$i_s = cV^{3/2} \tag{4}$$

However, this increase in electron current with V continues only until a certain limiting value, i_T, is reached which depends only upon the temperature. This is the *saturation electron emission which is a function of the temperature and of cathode area only.* It is this saturation current that obeys the Richard-

son equation. As has been shown by Langmuir, the electron current is limited at the lower anode voltages by a *space charge effect* resulting from the repulsive forces between electrons in the space between the electrodes, and on the basis of Coulomb's law, he was able to derive the conclusion that the relation between space charge limited current and anode voltage should be of the form stated in eq 4 where the exact value of c is determined by the relative configuration and shapes of the electrodes.

Thus for 2 infinite parallel planes separated by a distance x (in centimeters) the maximum current density i_s (in amperes per square centimeter) is given by

$$i_s = 2.33 \times 10^{-6}\, V^{3/2}/x^2$$

where V is the potential difference in volts.

Similarly, for a filamentary cathode of radius a placed in the axis of a cylinder of radius r, the maximum electron current per unit length of time is given by

$$i_s = 14.65 \times 10^{-6}\, V^{3/2}/r$$

for the case where r is more than 10 times greater than a.

From these considerations, it is evident that for any given temperature of the cathode, the temperature limited emission, i_T, may be observed only if the anode voltage is greater than the value defined by the relation

$$V = (i_T/c)^{2/3}$$

corresponding to space charge limitation.

As the anode voltage is increased beyond this value, there is observed a further slight increase in emission because of the increase of field strength at the cathode. A theoretical explanation of this phenomenon was suggested first by Schottky (1914) and hence it is known as the *Schottky effect.* According to this theory, the emission, i_V, at any field strength, E, is related to the emission, i_0, at zero field strength (which is the value to which the emission equations apply) by the relation

$$i_V = i_0 \epsilon^{4.39\sqrt{E}/T} \qquad (5)$$

Since for any given arrangement of electrodes E is proportional to V, eq 5 leads to the conclusion that at anode voltages in excess of those required to overcome space charge, log i_V should increase linearly with $\sqrt{V}/T$. For tungsten and similar pure metallic thermionic sources, it has been shown that eq 5 is valid over the range of voltages used in making observations on electron emission. Therefore, the emission at zero field strength, that is, the value to be used in eqs 1 and 2, is obtained from the straight line plot of log i_V versus $\sqrt{V}$ by extrapolating to $V = 0$.

In the actual technique for obtaining accurate emission data, it is necessary to take care of the 2 very important factors that influence the magnitude of the emission. The first factor involves precautions regarding the removal of adsorbed and occluded gases from the emitting surface, and the maintenance of as nearly perfect vacuum conditions as possible. The second factor is the need of an accurate temperature scale for the surface under investigation. A further point in connection with the accurate determination of the temperature is that regarding corrections for end-losses where filaments are supported by leads. Information on these topics is now available in several publications.

Table II—Emission Data for Homogeneous Metallic Emitters

Metal	A	$b_0 \times 10^{-4}$	ϕ_0	I_T	T
Cs	162	2.10	1.81	2.5×10^{-11}	500
Mo	60.2	5.09	4.38	2.34×10^{-3}	2,000
Pt	1.7×10^4	7.25	6.27	9.2×10^{-10}	1,600
Ta	60.2	4.72	4.07	1.38×10^{-2}	2,000
W	60.2	5.24	4.52	1×10^{-3}	2,000
Th	60.2	3.89	3.35	4.3×10^{-3}	1,600
Zr	330	4.79	4.13	8.5×10^{-5}	1,600

Table II gives electron emission constants for some of the metals for which accurate values are available. Only values of A and b_0 are given, not those of a and b since nearly all investigators now use eq 2. The second last column gives the value of emission in amperes per square centimeter at the absolute temperature, T, given in the last column.

Thoriated Tungsten Cathodes

In 1913 Langmuir and W. Rogers discovered that by proper thermal treatment of a tungsten wire containing 1 to 2 per cent of thoria (ThO_2) a very much higher electron emissivity could be obtained than that observed from filaments of pure tungsten. As was shown by Langmuir, this increased activity is due to the presence of a layer of thorium atoms adsorbed on the surface of the tungsten. The procedure finally adopted for obtaining thorium emission is as follows:

1. By flashing the filament for a minute or 2 at temperatures higher than 2,700 deg K, some of the thoria is reduced to thorium. Because of the high temperature any thorium atoms that diffuse to the surfaces are immediately evaporated there, so that the emission is substantially that of tungsten.

2. If now the temperature is decreased to 2,000–2,200 deg K, the rate of diffusion is still quite high, but the rate of evaporation is decreased to such an extent that thorium atoms can accumulate on the surface as an adsorbed layer.

In order to observe the rate at which the surface becomes covered with thorium atoms at these temperatures, the temperature is lowered at frequent intervals during the activation process to such a value (1,600 deg K or less) that the rate of diffusion also becomes negligibly small. In this manner a plot is obtained of emission at a given testing temperature as a function of the time at the activating temperature. Evidently such a curve should make it possible to calculate the rate at which thorium atoms diffuse to the surface at any temperature; similarly by means of a deactivation curve at temperatures between 2,200 and 2,700 deg K it should be possible, from a knowledge of rates of diffusion to the surface (as extrapolated from the values obtained at lower temperatures), to derive rates of evaporation of thorium atoms at different temperatures.

The foregoing involves as a preliminary and

very essential step the derivation of a relation between the observed emission (which shall be indicated by i) and the fraction of the surface covered with thorium atoms (θ). Langmuir assumed a linear relation between $\log i$ and θ and that $\theta = 1$ for maximum emission. On this basis he derived relations for the diffusion constant and rate of evaporation as a function of the temperature, T. However, as has been shown by the recent work of Brattain and Becker (1933) and confirmed by Langmuir (in a paper recently published in *Physical Review*), the assumption made by the latter in his 1923 paper is not justifiable. It seems highly probable that the maximum emission (i_m) is obtained for $\theta = 0.7$ approximately. In view of the present uncertainty in the exact value of θ for $i = i_m$, the method of interpretation suggested by Becker is very useful. According to the latter, the amount of thorium on a tungsten surface is defined by a quantity, f, and it is found empirically that if f is assumed to be 1 for $i = i_m$ at any temperature, then the emission for any surface for which f lies between 0 and 0.8 or 0.9 is given by an empirical relation of the form

$$\frac{\log i - \log i_W}{\log i_m - \log i_W} = 1.13\,(1 - \epsilon^{-2.38f})$$

where

i_W = emission from pure tungsten
i_m = maximum emission from tungsten covered with thorium

both measured at the same temperature.

According to Brattain and Becker, the emission from thoriated tungsten as a function of f and T is given by the relation

$$\log (i/i_W)_T = 6.54k(1 - \epsilon^{-2.38f})$$

where

$$k = 1 - 1.42 \times 10^3 \left(\frac{1}{1{,}274} - \frac{1}{T}\right)$$

The values thus obtained agree satisfactorily with those obtained previously by the author and Mrs. J. W. Ewald and lead to the values of A and b_0 in eq 2a for different values of f shown in Table III. The fourth column gives the emission in amperes per square centimeter at $T = 1{,}274$, and the last column the logarithm of the ratio between the emission for thorium covered and pure tungsten at $T = 1{,}274$, for each value of f. While these values are based upon emission data taken with an applied potential of 100 volts, observations by Brattain and Becker indicate that both A and b_0 increase with decrease in applied potential, the relative magnitude of this decrease being least for $f = 1$ (where there is practically no change in A and only a slight increase in b between 100 and 10 volts) and greatest at $f = 0.6$ and $f = 0.3$.

Table III—Emission Constants for Thoriated Tungsten Filaments

f	$b_0 \times ^{-4}$	A	$10 + \log I_{1,274}$	$\log(I/I_W)_{1,274}$
0.0	5.20	69	0.32	0.00
0.1	4.75	48	1.71	1.39
0.2	4.39	36	2.80	2.48
0.3	4.11	29	3.66	3.34
0.4	3.89	24	4.34	4.02
0.5	3.71	21	4.88	4.56
0.6	3.58	19	5.30	4.98
0.7	3.46	17	5.65	5.33
0.8	3.39	16	5.86	5.54
0.9	3.34	15.6	6.02	5.70
1.0	3.32	15.5	6.08	5.76
1.2	3.43	20	5.87	5.55
1.4	3.61	37	5.46	5.14
1.6	3.74	53	5.20	4.88
1.8	3.79	61	5.11	4.79
2.0	3.80	65	5.07	4.75

It may be observed that for $f = 1$, at $T = 1{,}274$, the maximum emission from thoriated tungsten is $10^{5.76} = 5.75 \times 10^5$ times that of pure tungsten. At higher temperatures this ratio is lower, because of the difference in values of b_0.

With regard to the mechanism of diffusion of thorium, Langmuir points out in his most recent paper that "It seems reasonable to assume (on the basis of the results obtained by a number of investigators) that a large fraction of the thorium which arrives at the surface travels from the interior along grain boundaries, and then spreads out over the surface." That is, at lower temperatures the coefficient of diffusion along the surface of grains is considerably greater than that of diffusion from within the grains themselves. It is only at 2,300 to 2,400 deg K and higher temperatures that the latter becomes of importance in governing rates of deactivation. Langmuir finds that the coefficient of surface diffusion and rate of evaporation of thorium from the surface are, in each case, functions of both f and T. Hence the conclusions given in the 1923 paper regarding the values of diffusion constants (which at that time were calculated on the assumption that diffusion occurs only in the solid lattice of tungsten atoms) and values of rates of evaporation must be disregarded in view of the more recent work.

It should be noted in this connection that other rare earth oxides (such as those of cerium, lanthanum, yttrium, uranium, and zirconium) added to tungsten and molybdenum show characteristics similar to those exhibited by thorium on tungsten, but in none of these cases is the emission at any given temperature as great. The emission phenomena for films of thorium on molybdenum are also quite similar; and while the emission per watt input is approximately the same at lower temperatures as for thorium on tungsten, it is not possible to obtain as high emission at temperatures higher than 1,700 deg K on account of the extremely high rates of diffusion and of evaporation.

The data given by Brattain and Becker show that for $f = 2$, the emission is approximately $^1/_{10}$ of that observed for $f = 1$ and approaches very closely that obtained by Zwikker (1926) for solid thorium.

Oxide Coated Cathodes

The oxide coated type of cathode, while of greatest importance from the technical point of view, presents the most complex problems from the purely scientific point of view. As has been mentioned previously, the emission from oxides of the alkaline earth metals (CaO, SrO, and BaO) was observed first by Wehnelt (1904). The high value for the emission per watt input together with the high absolute magnitude of the emission obtainable at temperatures at which

the life is very long, led to the adoption of this type of cathode in the various types of electronic devices useful in industrial applications.

Various methods have been used for the preparation of filaments coated with the oxides mentioned in the preceding paragraph and these are described in detail in technical literature (see bibliography at end of article). The present practice consists in general in the use of nickel, nickel alloy, tungsten, or molybdenum as core metal upon which a coating of either mixed oxides or oxide of barium is put in the form of carbonates or nitrates or a mixture of these. The water used in forming the coating, as well as some of the carbon dioxide and oxides of nitrogen are driven off by a preliminary heating in air; after the filament is introduced into the tube, the latter is exhausted well, following which the filament is subjected to a final activation process. During this treatment, combined carbon dioxide and oxides of nitrogen as well as residual water are driven off first so that the pure oxides are left. Then either the filaments are heated to a high temperature, which presumably causes a reduction of some portion of the oxides to their respective metals, or an electron current is drawn from the cathode by applying a rather high positive potential gradient. During this process the emission increases greatly and the treatment is continued until the maximum emission is obtained. As will be pointed out later, there are good reasons for assuming that during this treatment with anode voltage the oxides are decomposed electrolytically with formation of their respective metals at the surface of the core and subsequent diffusion of the metal atoms to the surface of the oxide. Often a combination of the thermal and electrical methods of activation is used.

Before discussing the various views held regarding the exact nature of the emission phenomena and of the mechanism of activation, some of the actual emission data obtained with cathodes of the oxide coated type will be presented briefly.

The behavior of these cathodes is so different from that of filaments of pure metals that it has been found very difficult to obtain precise data on emission constants comparable with those obtained for pure metals or even thorium on tungsten. The emission from oxide coated cathodes increases very rapidly with voltage, especially at higher temperatures, even when it is considerably below the limit set by space charge effects. Furthermore, the emission is likely to change with time, and there are pronounced fatigue effects. Also the composition and mode of application of the materials used and subsequent activation treatment affect profoundly the maximum emission obtainable at any temperature. In general, it may be stated that increased technical experience gradually has produced much more active filaments than those available at an earlier period. Thus, according to data published by H. D. Arnold (1920) the emission from a mixture of barium and strontium oxides at a temperature of 1,000 deg K is about 10×10^{-3} amp per square centimeter, while according to C. Davisson (1928) the emission from the same composition at the same temperature is about 100×10^{-3} amp per square centimeter. Rothe (1926) has published values of emission as high as 800×10^{-3} amp per square centimeter obtained at this temperature. Table IV gives a few of the more recent values of emission constants for oxide coated cathodes. As shown there, the work function for oxide coated cathodes is about 1 volt or even lower, while the values of A range from 0.24 to 10^{-4}.

Figure 1 shows a curve of log I/T^2 versus $1/T$ for an oxide coated cathode calculated on the basis of the constants given by Davisson (1928). In the same figure are shown also similar curves for other emitting surfaces (including caesium on tungsten discussed in the subsequent section of this article). The upper limit of each plot (lowest value of $1/T$) as is shown corresponds to the melting point in the case of pure metals or to the temperature at which the rate of evaporation of surface films becomes very high.

From a practical point of view, the *efficiency of emission* (milliamperes per watt) as a function of power input (watts per square centimeter) is of very great importance. Figure 2 shows (on specially designed cross section paper) the emission as a function of power input for different oxide coated cathodes (curves A to D) and for thorium on tungsten and pure tungsten. Curve A corresponds to data obtained with the best of oxide coated cathodes in 1923 and is taken from a paper published by R. W. King, of the Western Electric Company, while curve B corresponds to the data given by Davisson for oxide coated cathodes produced by the same company in 1928. The data used in plotting curves C and D were kindly furnished by G. R. Shaw, of the R.C.A. Radiotron Company, and correspond to the values for the emission observed on 2 different commercial types of radio tubes as made at the present time.

Operating points in each case in Fig. 2 are indicated by circles. Thus thoriated tungsten cathodes are operated at about 25 ma per watt, while in the case of curves A and B the efficiencies obtained were about 50 ma per watt. The higher emission efficiencies shown in curves C and D are probably to a large extent the result of improved tube design which makes it possible to operate the filaments at a given temperature with a very much lower power input. Thus with an oxide coated filament an increase in temperature of about 300 deg C would cause approximately a hundredfold increase in emission; therefore the higher emission observed on curves C and D

Table IV—Emission Constants for Mixture of Barium and Strontium Oxides and Emission at 1,000 Deg K

Year	Source	A	$b_0 \times 10^{-4}$	ϕ_0	I(Milliamperes Per Square Centimeter)
1925	Koller	1.07×10^{-3}	1.21	1.05	6.6
1926	German tube	9.6×10^{-4}	0.953	0.82	69
	German tube	5.7×10^{-4}	0.849	0.73	118
	German tube	9.8×10^{-5}	0.627	0.54	185
	German tube	1.6×10^{-2}	1.189	1.02	110
	Dutch tube	0.24	1.324	1.14	430
1927		2.97×10^{-2}	1.58	1.36	4.1
1928	Davisson	1.0×10^{-2}	1.16	1.00	92

could be accounted for by an increased temperature of operation at the *same power input*, as compared with previous tubes.

In this connection it should be pointed out that the effect of plate voltage on the emission is much greater for composite filaments than can be accounted for on the basis of Schottky's equation. As has been shown in recent papers by Langmuir and J. B. Taylor for caesiated tungsten, and by C. G. Found for oxide coated nickel cathodes, the zero-field emission for such cathodes is probably as small as 10 per cent of the value obtained at zero field by an extrapolation, on the basis of Schottky's equation from data obtained at higher voltages. For this reason it is impossible to give values of emission constants for thoriated tungsten and oxide coated cathodes that are quite comparable with those obtained for pure metal surfaces.

The different views that have been advanced in order to interpret the activation and emission phenomena exhibited by oxide coated filaments will be considered next. Contributions toward the elucida-

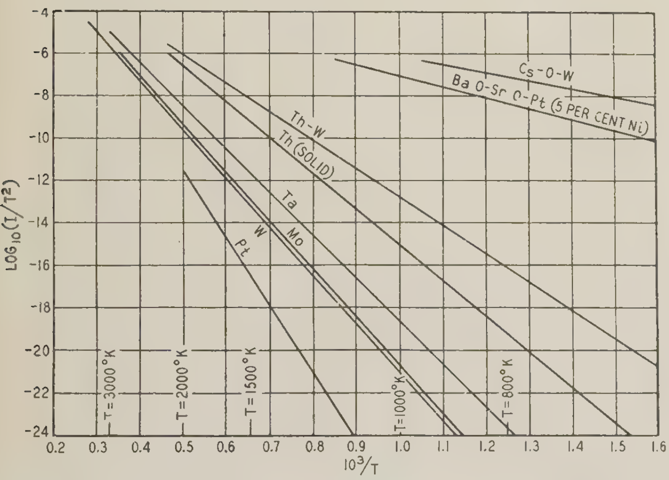
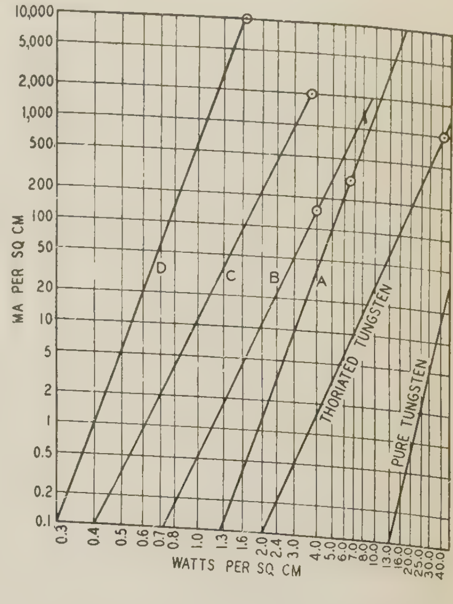


Fig. 1. Comparison of emission from coated filaments with that from pure metals

tion of these phenomena have been made by many investigators whose views are not always in agreement. However, since the most thorough investigations in this field have been carried out by J. A. Becker and his associates his conclusions will be summarized briefly in the following paragraphs.

The emission is ascribed to "an active layer at the outer oxide surface." This active material consists of metallic barium produced either by electrolysis of the oxide at the high temperature of activation or by chemical reaction between the oxide and the core material. The barium diffuses to the surface and forms there an adsorbed layer of ionized barium atoms (adions). These adions lower the work function for emission of electrons "which come from the underlying oxide." On this basis: "One might reasonably expect the activity to increase at a rate which is much more than proportional to the concentration of adsorbed barium, and that it might reasonably reach an optimum value for a monatomic layer before it decreases to its value characteristic of solid barium. Of course, eventually as the concentration of barium increases, the electrons must originate in the barium." The activity thus depends upon both the concentration of barium on the surface and upon the amount of barium or other metal (such as nickel) dispersed through the oxide. According to Becker there is no valid reason for assuming that the electrons are emitted by a layer of barium adsorbed on the core and that these electrons then must pass through the oxide layer (thousands of atoms in thickness) in order to reach the outer surface. In support of this theory is the fact that oxygen decreases the activity of a coated filament, as well as the observations on the conduction phenomena in the oxide as determined by the quantity of electricity sent through it and by the temperature.

Fig. 2. Emission from coated filaments as a function of power input



The foregoing view accounts for the observed increase in emission with relatively high anode voltages (this causes the deposition of barium at the core by electrolysis and the metal diffuses subsequently to the surface) and also for the decrease in work function during activation. At higher temperatures the barium evaporates from the emitting surface and leads to a deactivation of the latter. Furthermore, as shown by some recent work in the research laboratory of the General Electric Company by L. R. Koller, the barium may be sputtered off and made to deposit on an adjacent tungsten filament by positive ion bombardment.

A great deal of stress has been laid by some investigators, notably by Lowry, on the rôle of core material. The latter has observed that oxide coated filaments having cores made of "konel" (an alloy consisting of nickel, cobalt, iron, and titanium) behave quite differently from filaments with other cores. There is considerable evidence for the conclusion that in this case the barium is obtained by chemical reaction between the barium oxide and reducing metals in the alloy. According to Becker the differences in behavior of this cathode may be accounted for wholly by differences in rates of pro-

duction and diffusion of barium to the outer surface. For a similar reason, a core consisting of nickel to which a slight amount of metallic barium has been added also affects the rate of activation.

From the foregoing it is evident that the oxide coated cathode resembles the thoriated tungsten type in many respects. In each case, increased activity, as compared with the core or pure tungsten, results from the presence of adions on the outer surface. These adsorbed ions are obtained primarily by decomposition of the corresponding oxide and secondarily by diffusion of the metal atoms to the surface. In both cases, the finally observed emission depends upon the concentration of adsorbed atoms or ions present on the surface, which in turn is governed by rate of diffusion to the surface and rate of evaporation from the surface.

Caesium on Tungsten and Oxidized Tungsten

Emission phenomena for monatomic films of caesium adsorbed on tungsten and oxidized tungsten were investigated first by Langmuir and K. H. Kington in 1923. At about 700 deg K, the emission from a filament of tungsten completely covered with a layer of caesium atoms is 10^{-4} amp per square centimeter, which is about 10^{20} times that of pure tungsten at the same temperature. Denoting the fraction of the surface covered with caesium by θ, the value $\theta = 1$ is obtained in a bulb containing caesium at room temperature (0.10 mm vapor pressure) for temperatures of the tungsten filament as high as 800 deg K. At higher temperatures the value of θ decreases because of evaporation of caesium atoms, and the actual value obtained varies with both the temperature of the filament and the pressure of the caesium vapor (that is, the bulb temperature).

The following remarks on the emission phenomena exhibited by caesium films on tungsten are taken from a discussion by Langmuir (*Industrial and Engineering Chemistry*, v. 22, 1930, p. 390):

"This remarkable case of adsorption has been found to be due to the tendency of caesium atoms to lose their valence electrons to the tungsten. The work necessary to remove an electron from a caesium atom is measured by the ionizing potential, 3.9 volts. The affinity of a pure tungsten surface for electrons is measured by the heat of evaporation, 4.52 volts. Therefore, when a caesium atom comes into contact with a tungsten surface, the tungsten captures the valence electron and leaves the caesium as an ion, which is then held to the tungsten surface because of the negative charge which it induces (electric image force). This is confirmed by the fact that these adsorbed films are not formed if caesium is brought into contact with thoriated tungsten having an electron affinity of only 2.9 volts.

"If the filament temperature is high enough, the caesium ions evaporate from the filament as fast as the atoms strike the surface, but these ions are not formed if a fully thoriated surface is used. Thus with pure tungsten (or any material with electron affinity greater than about 4 volts, such as carbon, nickel, molybdenum, or platinum) the positive ion current that can be drawn with voltages great enough to overcome space charge is strictly independent of filament material or temperature (above a certain lower limit) or the electrode voltage, but is accurately proportional to caesium vapor pressure, p, being in fact given by

$$I = ep\,(2\pi mkT)^{-1/2}$$

where I is the current density, e the charge of an electron, m the mass of the caesium atom, and k is the Boltzman gas constant.

"The 2 curves marked 'Cs-W' in Fig. 3 [of this article] give the electron emission of pure tungsten filaments in presence of caesium vapor saturated at 20 deg and at 80 deg C. The falling off of emission as the temperature is raised above 700 or 800 deg K is due to the evaporation of caesium so that θ progressively decreases.

"When the current of caesium in the surface film is greater than corresponds to about $\theta = 0.20$, the electron affinity of the surface is less than 3.9 volts, so the caesium evaporates as atoms. Only at temperatures above about 1,200 deg K, when θ has fallen to 0.2, do all the atoms leave the filament as ions."

In Fig. 3 is shown also the variation with bulb temperature and filament temperature of the emission from a film of caesium on a tungsten filament that has been treated previously in oxygen to form an adsorbed layer of oxygen atoms. The latter stabilize, as it were, the caesium atoms on the surface and it is therefore possible to obtain higher emission from caesium on oxidized tungsten (Cs-O-W) than from caesium on tungsten (Cs-W) films. According to Kingdon the values of the emission constants for a completely covered surface of caesium on oxidized tungsten are: $A = 0.001$ amp/cm^2 deg^2; $b_0 = 8{,}300$; $\phi_0 = 0.695$ volts.

The *emission of positive ions* by the impact of caesium atoms on tungsten and other surfaces having a work function greater than 4 volts is an important effect. Similar observations have been made by T. J. Killian on the emission of positive ions from tungsten filaments in the vapors of rubidium and potassium, for which the ionization potentials are 4.16 and 4.32 volts, respectively.

Becker and especially Langmuir and Taylor have studied in great detail the evaporation of atoms, ion and electrons from caesium films on tungsten, as influenced by variations in θ and T. From these observations the 2 last named investigators have been able to deduce several interesting conclusions regarding the rate of migration of caesium atoms on the surface (surface diffusion) and the nature of the forces acting between atoms in an adsorbed film.

Effect of Gases and Positive Ion Bombardment

The effects of gases on the emission are of a twofold nature: Firstly, they may form *adsorbed monomolecular* or *monatomic* films on the surface of the cathode. Secondly, and especially with anode voltages in excess of a certain critical value (which varies

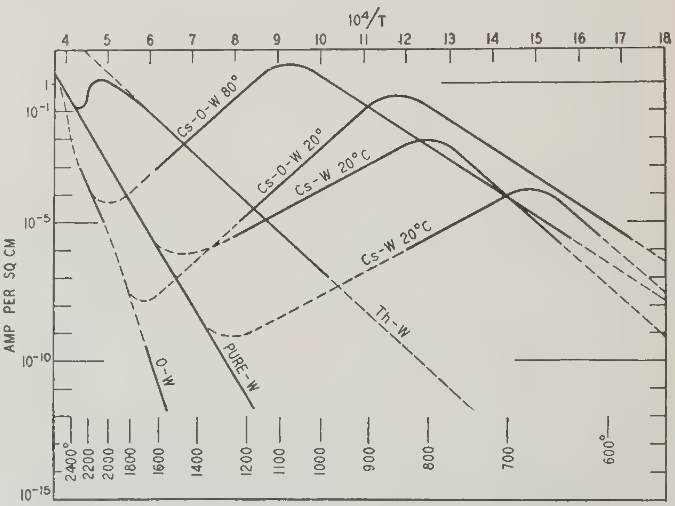


Fig. 3. Emission characteristics of monatomic films on tungsten

with the nature of the gas), positive ions are formed which sputter atoms off the surface of the emitter and thus may decrease the emission considerably. The first type of effect is illustrated by the observations on the enormously decreased emission from tungsten, thoriated tungsten, and other metals in a low pressure of oxygen, while the second type occurs, for instance, when an oxide coated or thoriated tungsten cathode is operated with an anode voltage in excess of about 30 volts in a low pressure of a rare gas such as helium, neon, or argon.

In a review such as this it is possible to refer briefly to only a few of the gas effects that have been observed, although the number of investigations dealing with this topic is quite extensive. (A summary of this work has been published by K. Becker in *Physikalische Zeitschrift*, v. 32, 1931, p. 489–507).

Oxygen on tungsten forms adsorbed layers which are quite stable up to temperatures of 1,800 deg K, and decreases the emission to about 10^{-5} of its value for the pure tungsten surface. This gas also decreases the emission from monatomic films of thorium and barium (as in oxide coated filaments) by forming adsorbed layers which are extremely difficult to remove. The work functions for such adsorbed films are very much higher than for the uncontaminated surfaces, increasing in the case of oxygen on tungsten to 9.26 volts, and in the case of oxygen on barium to 3.1 volts.

Carbon monoxide and carbon dioxide behave quite similarly to oxygen. The emission from tungsten is unaffected by nitrogen if low anode voltages are used, but is decreased by the use of higher voltages because, as shown recently by Langmuir, active nitrogen is formed which liberates oxygen from oxides on the leads and filaments. However, Kingdon has shown that in case of thoriated tungsten, nitrogen at a pressure of 0.0001 to 0.005 mm causes approximately a fivefold increase in emission.

In the case of metals that form nitrides and oxides (tantalum, zirconium, and hafnium) adsorbed films of oxygen and nitrogen decrease the emission, and it is therefore necessary to heat these metals to as high a temperature as possible for a long period in order to obtain the lowest values of work function (and highest emission). In all these cases it has been observed that the value of the constant A also decreases during degassing. In fact, as has been pointed out by L. Du Bridge, there seems to exist a linear relation between b_0 (or ϕ_0) and log A. However, the decrease in A is negligible in its effect on the observed emission as compared with the increase in emission due to decrease in b_0.

The effect of hydrogen on the emission from platinum was investigated first by Richardson in his earliest work, and has been studied more recently by Du Bridge. This metal *absorbs* hydrogen very readily, and at 1,033 deg C, 100 g may contain as much as 0.021 mg of hydrogen. As the gas is eliminated by continued heating, the electron emission *decreases* continuously and ϕ_0 increases from 4.7 volts to 6.27 volts for a well degassed sample. Tantalum shows similar behavior to platinum, in respect to both absorption capacity for hydrogen and the effect of the gas on the emission.

Iodine, phosphorus vapor, and similar electronegative gases decrease the emission from metals because of formation of adsorbed films of high work function. On the other hand, as mentioned already, vapors of the alkali metals increase the emission from metals of high work function by forming adsorbed layers having lower work functions.

The effects of bombardment by positive ions vary with the nature of the gas and that of the surface. In the case of pure metals, such as tungsten, molybdenum, and others, bombardment by positive ions of rare gases has no effect on the emission, but causes, of course, a mechanical disintegration of the cathode. As shown by Kingdon and Langmuir, positive ions of the rare gases and of caesium and mercury, remove adsorbed thorium atoms from a thoriated tungsten filament when the energy of the ions exceeds 50 volts, and A. W. Hull has observed (1928) that in this case a threshold voltage exists for each type of ion below which sputtering does not occur. Similar observations also have been made on oxide coated cathodes. It is this fact that has made possible the development of hot cathode gaseous discharge lamps such as those containing neon and sodium vapor.

Effect of Intense Electric Fields

The effect of fields of low intensity has been discussed in a previous section of this article. The interpretation given by Schottky is that the emitted electrons are attracted to the surface by image forces. While his equation is found to be valid for pure metal surfaces, deviations are observed at low field strengths in the case of composite surfaces; Becker and D. W. Mueller have ascribed these results to the superposition of a Schottky image force field and a field caused by the layer of adsorbed atoms. The possible causes of these observations have also been discussed by K. T. Compton and Langmuir without reaching any definite conclusion.

Under the action of very intense fields of the order of 10^6 to 10^7 volts per centimeter, it has been shown that emission of electrons occurs even with the cathode at room temperature. This is known as the "cold cathode effect" or "autoelectronic" emission, and is observed with moderate anode potentials (1,000 to 10,000 volts) when a fine point is used as cathode. Empirically it is found that the emission varies exponentially with the field strength. An interpretation of the phenomenon has been given by R. H. Fowler and L. Nordheim (1928–9) on the basis of the theory of wave mechanics.

According to the classical point of view, the electrons in a metal at room temperature are prevented, because of their low kinetic energy, from leaving the surface by a potential barrier corresponding to the work function for emission. At higher temperatures, more and more electrons acquire sufficient kinetic energy to *pass over* this barrier, and hence follows the observed increase in emission with temperature. According to the new point of view, an intense electric field decreases the width of the potential barrier so that it becomes possible for an electron of low kinetic energy to *penetrate* it. The probability of the occurrence of this "tunnel effect"

increases rapidly with field strength and therefore it becomes possible to obtain emission at temperatures as low as room temperature if the field be increased sufficiently. This is a crude explanation of a phenomenon of which a more accurate discussion would require a great deal more space.

The relation derived by Fowler and Nordheim is of the form

$$I = \frac{CF^2}{\sqrt{\phi_0}} \epsilon^{-r\phi_0^{3/2}/F} \tag{6}$$

where C and r are material constants, F is the field strength and ϕ_0 is the work function as determined from the variation in emission with temperature. Experimental data have been shown to be in satisfactory agreement with this theoretically deduced relation.

Concluding Remarks

Obviously, in an article of this length it has been possible to present only some of the more important observations and conclusions that have been obtained from investigations in this field. No mention has been made of the relation between thermionic and photoelectric effects, and only a brief reference has been made to the phenomena of positive ion emission. For a more complete discussion of these topics as well as of those touched upon in the present summary, the reader may consult the following references:

1. O. W. Richardson, Thermionic Emission, Longmans, Green and Company, London (1916).

2. S. Dushman, Reviews of Modern Physics, Vol. 2, 381 (1930). A review of the subject up to that date.

3. W. S. Stiles, Department of Scientific and Industrial Research, Special Report No. 11, London, England, 1932. "A survey of existing knowledge (on thermionic emission) with particular reference to the filaments of radio valves.

4. K. T. Compton and I. Langmuir, Review of Modern Physics, 3, 191 (1931). A review of gas discharge phenomena in general, including some of the topics discussed by the writer.

No mention has been made of the numerous treatises in German, especially that by Schottky, but references to these are given in the publications mentioned.

Insulator Arcover in Air

Although much is yet unknown about the many factors concerned in insulator arcover, humidity tests presented here lead to a theory of arcover. The geometrical design of the insulator is shown to be a minor factor at power frequencies, but of importance for withstanding impulse voltages.

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In many respects, the old problem of insulator arcover is in the same state of solution after nearly 40 years as it was in the early days of high voltage apparatus construction, for satisfactory explanations of some of the observed phenomena still are lacking. In this paper it is shown from test results that atmospheric humidity affects the arcover strengths of insulating materials in a somewhat erratic manner and quite independently of whether the material is hygroscopic or "greasy." Other factors that have large influences are enumerated and explained, and insulators whose arcover strengths are independent of humidity are described. A theory of arcover is offered, and test data obtained with continuous and impulse voltages, as well as with alternating voltages, are presented. Laboratory tests of commercial insulators are analyzed and correlated with the fundamental properties of the insulations. Briefly, it is shown that:

1. Atmospheric humidity may reduce the arcover strength of a clean, smooth surface to $^1/_3$ of the breakdown strength of the parallel path in air. The remedy is to break up the smooth surface into several shorter lengths by means of ribs or flanges of the same insulating material. If the flanges are spaced uniformly and sufficiently close together, they may offset entirely the effect of the atmosphere.

2. Correction of test data to "standard conditions" by means of the air density δ, whether necessitated by pressure or temperature differences from standard, is likely to lead to error if a linear relation is assumed.

3. Dirt, salt, water, and other semiconducting coatings give a real significance to surface resistance, but the latter need be calculated only as a length divided by circumference, integrated over the entire surface, instead of in actual ohms which may vary over a wide range and not affect the arcover strength.

4. Commercial insulators of approximately 1-ft arcing length have a 60-cycle arcover voltage when clean and dry of somewhat more than $^1/_4$ the ideal puncture voltage of a 1-ft air gap between plate electrodes. Suspension insulators of 12-ft length tested horizontally by Angus[20] have an arcover strength of only $^1/_5$ of that for the ideal air gap. One may obtain the ideal value for air by extrapolating the upper curve of Fig. 3. If transmission line voltages are to be pushed to considerably higher magnitudes than at present, some advantage no doubt will have to be taken of the greater arcover strength obtained by providing a uniform field in the neighborhood of each insulator. Another improvement can be obtained by more

Full text of a paper recommended for publication by the A.I.E.E. committee on power transmission and distribution, and scheduled for discussion at the A.I.E.E. Pacific Coast convention, Salt Lake City, Utah, Sept. 3–7, 1934. Manuscript submitted April 30, 1934; released for publication, May 24, 1934. *Not published in pamphlet form.*

closely spaced flanges, and the direct wetting by rain may need to be prevented.

5. Although impulse voltage searches out to a considerable extent certain weaknesses in insulator design, it is well to recognize that the numerical value usually exceeds the 60-cycle arcover voltage; hence, in the end, the latter may be the critical one.

6. Laboratory test reports should be more complete, including such essential information as the rating of the testing source and its impedance, and the protective resistance in series with the insulator under test. It is believed that many discrepancies will be explainable if this procedure is followed.

An Unexplained Phenomenon

As an example of one of the unexplained phenomena, 2 metal plates, Fig. 1a, approximately flat but with smoothly rounded edges, and supported parallel to each other 1 cm (0.394 in.) apart, can withstand an alternating or a continuous voltage having a maximum value of 30 kv before a spark will pass between the plates. (Crest values of alternating voltage will be used exclusively herein in order to facilitate comparison with continuous and impulse voltage tests.) A piece of insulation carefully shaped into the form of a right cylinder 1 cm long and placed between the plates, Fig. 1b, although theoretically having no disturbing influence on the electric field, will be found by test to have reduced the breakdown strength of the gap to perhaps 15 kv or less. A satisfactory reason for this behavior is not obvious, and in fact is not known.

Surface Effects

By means of the simple testing apparatus of Fig. 1 such uncertainties as nonuniform voltage distribution over the insulator surface, electric field distortion in the medium outside, corresponding field distortion inside the insulation material, and the influence of parasitic capacitance are eliminated.

Atmospheric humidity has become recognized as an important factor in the arcover strength of most insulation, but the exact degree of its influence is uncertain. Figure 2, curves A to G, gives results obtained by 2 different investigators[3,6] who used alternating voltages of power frequency. Space does not permit a full discussion of the advantages of plotting relative humidity as a coördinate in place of one or other of the absolute humidity scales. The chief reason for its use here is to avoid the discontinuity above 100 per cent humidity that is always bothersome with an absolute scale. A check of the values of Fig. 2 in the laboratory yields points well scattered over the area included between the 2 sets of curves, most points, however, lying in the lower part of the area. It was not possible to duplicate Ritz's curves A to C which are higher than those obtained by any other experimenter, and there is reason to believe that they are peculiar to his apparatus, which was mechanically the most perfect of all. A very elaborate test was made on heat-resistant glass in which the sample after first being baked in a vacuum at 300 deg C for 2 hours was next supplied with air at atmospheric pressure in the same apparatus. The air before being admitted was dried carefully by freezing at liquid air temperature. An arcover strength of this sample equal to the strength of the air gap alone was observed. This and a somewhat similar test made by Inge and Walther[11] seem to be the only results thus far obtained agreeing with Ritz's extraordinary observations, and even then his unusually high figures were not checked at humidities other than zero.

Such surface characteristics as roughness, oiliness and absorptiveness have no important influence on arcover strength. Tests show conflicting results, but these easily may be attributed to other effects. Rice[13] found that surface coatings of oil, grease, or varnish on insulation give rise to improved arcover strength, but there are too many other factors in-

3. For all numbered references see bibliography at end of paper.

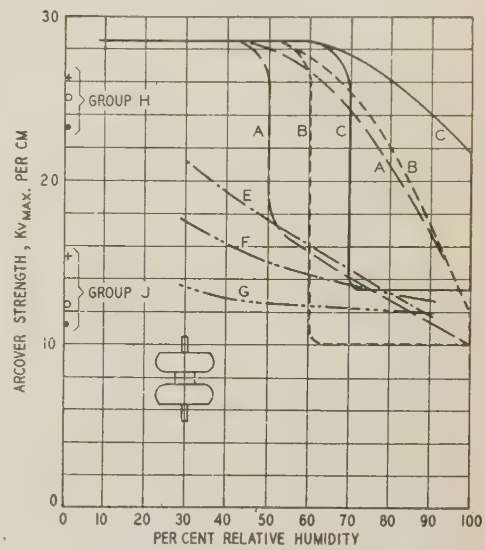

Fig. 2. Effect of relative humidity on arcover strength

Curve A. Paraffine right cylinder, Rogowski[2] electrodes, sparking distance 3.0 cm 50 cycles, series resistance 400,000 ohms, 45 to 20 deg C, 76 cm, absolute humidity constant at 1.8 cm mercury; from Ritz.[3] The uppermost horizontal line of curves A, B, and C corresponds to the strength of the air gap alone

Curve B. Glass right cylinder, conditions as for A; from Ritz

Curve C. Bakelite right cylinder, conditions as for A; from Ritz

Curve E. Paraffine right cylinder, flat electrodes with rounded edges; sparking distance 3.0 cm, 50 cycles, 20 deg C, 76 cm; from Schwaiger[6]

Curve F. Glass and unglazed porcelain right cylinders, conditions as for E; from Schwaiger

Curve G. Shellac right cylinder, conditions as for E; from Schwaiger

Points, Group H. Paraffine right cylinder, flat electrodes with curved edges of 20 cm radius; sparking distance 3.0 cm, 20 deg C, 76 cm. Upper point, surge voltage (wave form not given); middle point continuous; lower point 50 cycles; from Inge and Walther[11]

Points, Group J. Glass right cylinder, conditions as for H; from Inge and Walther

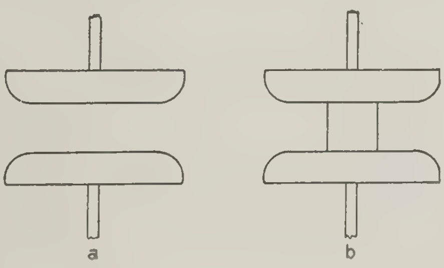

Fig. 1. Spark gap with plane parallel electrodes (a); and (b) same gap with insulation sample in place

volved in such experiments to lay much stress upon the results.

The terms "surface resistance" and "creepage distance" have been shown definitely to have no meaning in the "dry" arcover behavior of insulation, i. e., in the range of 0 to 100 per cent relative humidity, so long as no droplets of liquid appear on the surface of insulator or electrodes. The situation, however, is entirely different for wet, dirty, or salt-coated insulation according to Wood[1], who defines surface resistance as the integrated length-divided-by-circumference and proves it to be a practical measure of the arcover strength of complicated commercial insulators salt-coated. Tests in the high voltage laboratory of the California Institute of Technology on simple right cylinders coated with salt gave the same arcover potential per unit resistance as obtained by Wood.

Details of the Testing Gap and Testing Circuit

Electrodes of accurately flat form are unsuited to this type of arcover test because they produce an excessive stress in the air near their rounded edges. A much better contour has been suggested by Rogowski.[2] It is the same as an equipotential surface in the field between 2 thin flat sheet electrodes and was so chosen that the maximum stress in the air is nowhere appreciably greater than in the useful part of the gap. One such surface can be generated by rotating about the y axis the plane curve

$$x = 0.2385d \left[2.3026 \log \left\{ 4.83,5\left(\frac{y}{d} - \frac{1}{2} \right) \right\} - 2.4175 \left(\frac{y}{d} - \frac{1}{2} \right) + 8.71 \right]$$

where x and y are the ordinary variables and d is the desired length of spark gap in the same units. For other suitable equipotential curves the reader is referred to theoretical works on electrostatics. In order to complete the electrode its thickness should be made about $1.5d$, and a plane back may be used or the inside bored out to reduce the weight if of large size. It must be polished carefully and so maintained for all tests. The finished electrode resembles a door knob and may be used without great error for spark gaps from $^1/_2d$ to $2d$.

The mechanical fit between electrodes and insulation is of the utmost importance. Practically the whole range of observed arcover strengths, for a given relative humidity, Fig. 2, can be obtained by changes in the perfection of the fit between sample and electrodes, especially at the cathode. Ritz[3] secured test pieces made with optical precision and reports the best arcover strengths that have been observed below 70 per cent humidity, as shown by Fig. 2. Wax and oil as filters for the spaces left by poorly made ends of specimens are of little or no value because of their low dielectric constants.

Analogous to the Wagner[4] effect of protecting solid insulation from puncture by using high resistance electrodes is the insertion of resistance or reactance into the testing circuit to prevent arcover. Different experimenters use large, small, or medium capacity sources of voltage according to the available facilities in their respective laboratories. The results should not be expected to be comparable and can be compared legitimately only when all testing conditions are known, including impedance of the test circuit.

Geometrical Factors and Atmospheric Density

The free length has a strong influence on the arcover gradient. The upper curve of Fig. 3 shows how the breakdown strength of the spark gap alone varies

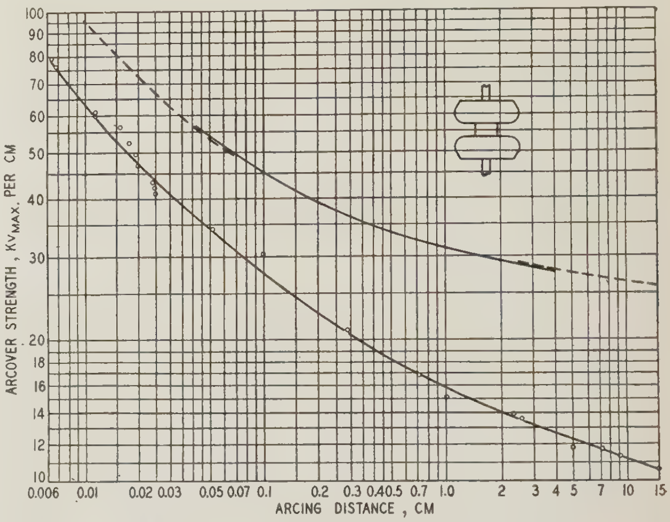

Fig. 3. Effect of sparking distance upon arcover strength

Lower Curve. Glass, "pyrex" and porcelain right cylinders between polished flat electrodes, relative humidity 60 per cent, temperature 20 deg C (approx.), barometer 76 cm, 50 cycles. Upper Curve. Air only, between polished flat electrodes. Left end from experiments of Liebig[5] with plane to sphere as electrodes (corrected for curvature of sphere). Middle from Ritz[3] 1932, Rogowski electrodes. Right end from Schumann,[7] flat electrodes with long radius edges

with the sparking distance. The lower curve shows the nice manner in which the arcover strength of a solid under constant atmospheric conditions parallels the curve for air alone.

The relative diameter of the specimen has no influence except that very slender fibers show somewhat higher arcover voltages than a larger cross section of the same material. Strips of paper tested in the long direction had arcover strengths practically equal to that of the gap alone.

Atmospheric pressure and temperature different from standard conditions usually are corrected for by the use of a relative air density factor δ which is $\frac{3.92b}{273 + t}$ where b is barometric pressure in centimeters of mercury and t is temperature in degrees Centigrade. It assumes linear variations of both effects. In Figs. 4a and 4b it is shown clearly that even for the breakdown strength of air alone the pressure effect is not linear and for arcovers it may be far from linear. Fig. 4c shows that the temperature effect curves bend the other way, hence a correction in which both temperature and pressure

change δ in the same direction and by similar amounts is fairly accurate, but considerable error will be made under other circumstances.

A complete set of curves for correction to standard temperature and pressure would be quite laborious to make or use, and other influences of uncertain nature cause individual readings to vary from each other by margins large enough to discourage attempts at great precision in calculations. It is recommended, however, that arcover data not be corrected to standard conditions, but, instead, presented as obtained.

A Theory of Insulator Arcover

The surface of a solid object is not what the eye sees, but rather a molecular pattern against which gas molecules from the surrounding atmosphere are held in corresponding pattern. The succeeding layers in the direction away from the solid differ little by little until they merge with the atmosphere itself, but the lowermost layers of gas molecules are as dense as though at a pressure of several hundred atmospheres

Langmuir[8] and Davisson and Germer[9] have given a great deal of information regarding such adsorbed layers of gas molecules. Most significant for present purposes is that a "clean" surface of glass in contact with the ordinary atmosphere holds to itself 100 times as many water as nitrogen molecules.

Glass is soluble in water, especially in the presence of carbon dioxide. Here, then, is the source of an electrolyte covering the surface of the glass insulator. This is confirmed by an experiment in which a glass specimen was washed thoroughly by rubbing with water and a mildly abrasive soap (such as mechanics use to clean the hands), after which it was dried in paper towels and not touched by the fingers. For 3 days it withstood an atmosphere of 85 to 90 per cent humidity without appreciable reduction in arcover strength; but finally the attack of the atmosphere aided by the heat of the arcs which occurred during the tests brought about the usual surface conditions and the arcover strength was reduced to that normally observed. A freshly drawn fiber of glass did not come to equilibrium with the atmosphere for about 24 hours.

The physical picture, then, of insulator arcover is that of a surface thinly covered by electrolyte. The applied voltage drives a current through the conducting medium, causes local heating, violent evaporation in patches and consequent alternate areas of high and low resistance. Arcs begin in the high resistance areas long before an arc would form simultaneously over the entire surface. When once an arc has formed, complete breakdown soon follows. Impulse arcover voltages are always higher than continuous or 60-cycle alternating voltages, and it may be assumed that the time-consuming nature of evaporation is an explanation of this.

That insulations other than glass behave similarly makes one search for another source of surface electrolyte. Minute dust particles, carbon dioxide from the air, and foreign substances not previously removed from the surface of the specimen are no doubt sufficient.

A bad mechanical fit between specimen and electrodes, especially at the cathode where spark formation always begins (according to Dunnington's[12] visual tests), affords air space where corona or a spark is sure to form at a voltage lower than the full strength of the test gap. Even an incipient spark, caused by short-circuiting part of the useful length of a specimen, can precipitate a complete arcover at subnormal voltage.

Table I—Arcover Strength of 7.6-cm Bakelite Rod, 260 Threads Per Inch, With Varying Relative Humidity

Temperature 20–22 deg C, barometer 74 cm, protective resistance 2 megohms, flat electrodes with curved edges, 50 cycles, transformer impedance 10,000 ohms

Crest Voltage, Kv	Crest Gradient, Kv Per Cm	Per Cent Relative Humidity
*137	18.0	29
156	20.6	29
147	19.3	33
153	20.2	37
150	19.7	39
156	20.6	50
144	18.9	50
155	20.3	77
*123	16.1	89
150	19.7	95
160	21.1	95
161	21.2	95
157	20.7	95
** 80	10.5	100
†155	20.3	74
‡139	18.3	100
160	21.1	Air alone

* Arc struck along the sample.
** Distilled water sprayed on sample previous to applying voltage. Droplets on both sample and electrodes.
† After drying for 1 hour in humidity as shown.
‡ Sprayed again more lightly with distilled water.

Table II—Arcover Strength of 9.1-cm "Pyrex" Rod, 260 Threads Per Inch, With Varying Relative Humidity

Temperature 16–19 deg C, barometer 75 cm, protective resistance 90,000 ohms, flat electrodes with curved edges, 50 cycles, transformer impedance 10,000 ohms

Crest Voltage, Kv	Crest Gradient, Kv Per Cm	Per Cent Relative Humidity
189	20.7	61
190	20.8	64
197	21.6	68
175	19.3	68
185	20.3	84
191	21.0	95
*123	13.5	95
191	21.0	Air alone

* Arc struck along the sample.

An Application of Fundamentals

That the shorter is the striking distance, the greater is the unit strength of an insulator surface is shown by

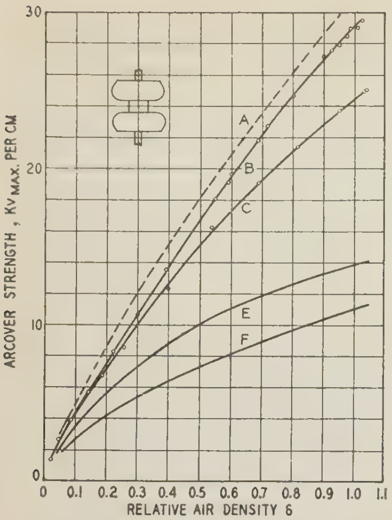

Fig. 4a. Effect of relative air density upon arcover strength

Constant temperature 20 deg C; 50 cycles
Curve A. Air only, sparking distance 1.0 cm, flat electrodes with curved edges of 20 cm radius from Inge and Walther[11]
Curve B. Pyrex right cylinder, sparking distance 0.73 cm, flat electrodes with rounded edges, relative humidity zero (approx.), series resistance 90,000 ohms, including transformer
Curve C. Glass right cylinder, sparking distance 1.04 cm, flat electrodes with rounded edges, relative humidity zero (approx.), series resistance as for B
Curve E. Glass right cylinder, sparking distance 1.0 cm, flat electrodes with curved edges of 20 cm radius, relative humidity zero (approx.), from Inge and Walther
Curve F. Glass right cylinder, sparking distance 3.0 cm, flat electrodes with curved edges of 20 cm radius, relative humidity zero (approx.), from Inge and Walther

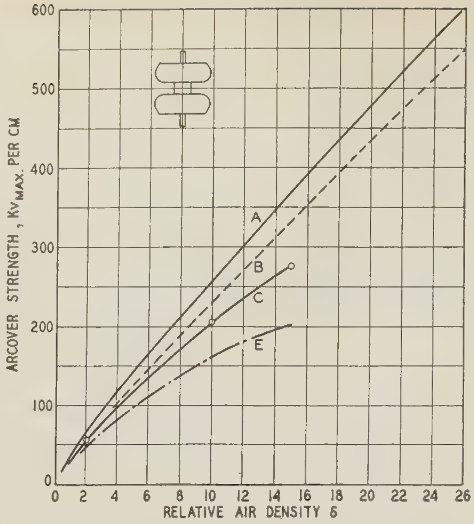

Fig. 4b. Effect of relative air density upon arcover strength

Constant temperature 20 deg C; 50 cycles
Curve A. Air only, sparking distance 0.3 cm, Rogowski electrodes; from Reher[10]
Curve B. Air only, sparking distance 1.0 cm, Rogowski electrodes; from Reher
Curve C. Hard rubber right cylinder, sparking distance 0.3 cm, relative humidity zero (approx.), Rogowski electrodes; from Reher
Curve E. Glass right cylinder, sparking distance 1.0 cm, relative humidity zero (approx.), values extrapolated from the works of several investigators

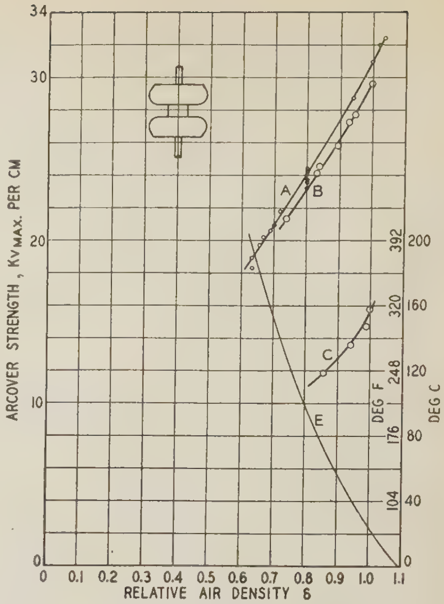

Fig. 4c. Temperature effect of relative air density upon arcover strength

Constant barometer 76.0 cm, 50 cycles
Curve A. Air only, sparking distance 1.0 cm, Rogowski electrodes, series resistance 120,000 ohms
Curve B. Pyrex right cylinder, sparking distance 0.73 cm, flat electrodes with rounded edges, relative humidity zero (approx.), series resistance 90,000 ohms
Curve C. Pyrex right cylinder, sparking distance 2.62 cm, flat electrodes with rounded edges, relative humidity 40 per cent
Curve E. Temperature deg C against relative air density, for convenience

Fig. 3. Rice[13] made use of this fact by stacking alternate glass and metal disks, the latter larger in diameter, forming several high strength samples in series, with electrodes between. He soon discovered, however, that alternate glass disks are better. There were 2 defects in his model. The glass disks were not flat enough to fit together well and they were too thick ($^1/_{16}$ in.). Tables I and II give test results for a bakelite and a "pyrex" rod, respectively, each having cut on its surface a screw of 260 threads per inch (102 per centimeter) for the entire length. Both ends carefully were fitted to the electrodes. The arcover potential per unit length of each is practically independent of humidity, showing the effect of flanges breaking up the surface into short lengths. Flanges provided on commercial insulators have a similar function: When the insulator is clean and dry they break up its length into many shorter insulator surfaces in series, the flanges themselves acting as new electrodes. The effect of flanges is quite different when the insulators are wet or dirty: They then serve to increase the surface resistance as previously described under "surface effects"; thus they have a double duty.

It is now easy to set up a rule for the best spacing of flanges. First determine the total length of the surface between the nearest electrodes. Find the arcover kilovolts per centimeter from Fig. 3 for the air gap alone of that length; multiply the value thus found by 3 and find on the same curve the corresponding length. It is the best spacing of flanges. As an example, suppose the distance between electrodes is 6 in. (15 cm). The corresponding unit strength of the air gap is 26 kv per centimeter, and $3 \times 26 = 78$. The length of air gap having 78 kv per centimeter breakdown strength is 0.015 cm or 0.006 in. It would be difficult to provide ribs or flanges at such minute spacing; hence it must not be expected that commercial insulators will have the same arcover strength as an equal length of air gap. The ratio 3 as just used is obtained from Fig. 2 in which the arcover strength for 100 per cent humidity is about $^1/_3$ that for the air gap alone.

Brasch and Lange[14] used the principle of uniformly spaced flanges in the construction of a 2.4-megavolt vacuum tube. Ritz[3] found that laminated paper rods in which the sheets were perpendicular to the axes had arcover strengths equal to the air gaps even in an atmosphere of 100 per cent humidity. Cotton tapes and string show similar properties.

A much more easily constructed test arrangement than those previously described and one which has many of the properties of a commercial pin or even suspension insulator was reported by Littleton and Shaver.[16] It consists of a rod of the test insulation

Table III—Influence of the Intervening Insulation Upon the Dry Arcover Voltage of 2 Similar Shield Rings

Diameter of rim material $2^{1}/_{2}$ in., outside diameter of entire ring 22 in., depth of ring fastening below rim $6^{1}/_{2}$ in., protective resistance zero, transformer 1,000 kva 1,000 kv, 50 cycles, 16 per cent impedance

Minimum Sparking Distance, Cm	Crest Voltage, Kv	Crest Gradient, Kv Per Cm	Per Cent Relative Humidity	Temperature, Deg C	Barometer, Cm Hg	Nature of Insulation
71	515	7.25	77	23	74.5	$3^{1}/_{2}$-in. glazed porcelain tube 105 cm long
102	710	7.0	77	23	74.5	Same tube
100	720	7.2	77	23	74.5	3 $^{1}/_{4}$-in. cotton ropes, each 130 cm long
100	720	7.2	77	22	74.5	8 10-in. standard suspension units spaced $4^{3}/_{4}$ in.
100	720	7.2	72	22	74.0	*7 high strength fog type units spaced $6^{1}/_{2}$ in.

* Data from tests by R. J. C. Wood, not published.

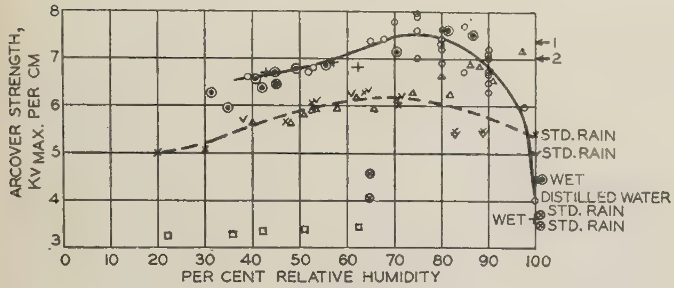

Fig. 5. Effect of atmospheric humidity upon the arcover strength of 3 types of commercial insulator; also rods with wire electrodes

o Glass rod $1^{1}/_{16}$ in. diameter; No. 8 AWG copper wire electrodes spaced 11.6 cm, 19 to 20 deg C, 74.5 cm mercury, 50 cycles

△ Pyrex rod 0.90 in. diameter; No. 6 AWG copper wire electrodes, spaced 35.5 cm, 21.7 to 30.2 deg C, 76.0 cm, 60 cycles; from Littleton and Shaver[16]

× Suspension string of 3 10-in. units, dry striking distance 49 cm, 25 deg C, 76.0 cm, 60 cycles; from Peek[15]

□ Apparatus bushing (not oil filled), bare conductor in place; striking distance 80 cm, wet or dry, 25 deg C, 76.0 cm, 60 cycles; from Frey and Hawley[17]

+ Apparatus bushing, as above; striking distance 12.7 cm; from Frey and Hawley

v Suspension string of 3 10-in. units; dry striking distance 49 cm; 30 to 31.5 deg C, 76.0 cm, 60 cycles; from Lloyd[18]

←1 Suspension string of 3 10-in. units spaced $5^{3}/_{4}$ in.; dry striking distance 49 cm, surge voltage of 2-μ sec front; from Torok and Archibald.[19] Same value wet or dry

←2 Suspension string of 18 10-in. units spaced $5^{3}/_{4}$ in., dry striking distance 265 cm, surge voltage of 2-μ sec front; from Torok and Archibald. Same value wet or dry

◉ Pyrex pin type insulator; striking distance 13.2 cm, 10.6 to 26.8 deg C, 76.0 cm, 60 cycles; from Littleton and Shaver

⊗ Upper points string of 10-in. units (vertical) dry; arcing distance 100 in., 60 cycles

⊗ Lower points outdoor pedestal type insulator (vertical) dry; arcing distance 100 in., 60 cycles; from discussion by J. E. Clem of paper by Frey and Hawley[17]

near each end of which is wrapped snugly a piece of heavy copper wire.

The curve of arcover strength against relative humidity for this simple rod is identical in shape with that of the pin insulator or suspension string, and, perhaps even more important, the actual arcover potentials per unit length of arcing distance resemble each other very closely as shown in Fig. 5.

Commercial Insulators

Technical literature seems to abound in reports of insulator tests that attempt to prove the differences between this and that shape, size or arrangement. The striking fact, however, is their similarity. Figure 5 is a collection of tests from many sources, assembled to show this similarity. The solid curve was drawn for a Littleton and Shaver type glass rod specimen 11.6 cm long, the dashed curve for a suspension string of 3 10-in. units. Other points have been inserted to show the remarkable agreement in arcover strength among commercial insulators of totally different designs. *The spread of the points in any individual test is practically equal to the spread of points from radically different classes of structures.* The only offenders are the apparatus bushing, which, because of its internal electrode, behaves unlike any other insulator used in electrical engineering, and the rather long (100 in.) pedestal and insulator string which are actually out of the range of length represented by the other tests. Curves such as those in Fig. 5 can be drawn for insulators having approximately 100-in. arcing distance. They will show lower arcover strengths than the 12-in. insulators. Thus 2 prominent fundamental characteristics have been brought out. First, in dry arcover, different shaped insulators, exclusive of apparatus bushing, having the same arcing distance have roughly the same arcover strength, which is here expressed in kilovolts per centimeter. Second, the arcover potential per centimeter diminishes when the length is increased just as it does for the right cylinders in uniform fields, Fig. 3. Table III is given in order to show that even more drastic changes in the nature and form of the insulation do not influence the arcover strength in the dry test at 60 cycles when the electrodes have the form of shield rings. Impulse tests, on the contrary, are influenced strongly by the geometrical details of the insulator.

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A Glow Discharge Anemometer

A glow discharge at atmospheric pressure is responsive to air velocity, and may be used as an anemometer. The properties of such a glow are discussed in this paper, and data relating to glow current, voltage, glow length, and air velocity are presented. It is also shown that the glow discharge responds to rapid fluctuations in air velocity and is therefore a practical device for investigating turbulence. A comparison of such an anemometer with the previously used hot wire method is given.

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RECENT aerodynamical research of both theoretical and experimental nature has indicated the important influence which air turbulence has on wind tunnel measurements. Experimental quantities, the lift and drag coefficients, are materially affected by the existence of small fluctuations superposed on the measured stream velocity. Moreover, these fluctuations in velocity, constituting turbulence, are characteristically of relatively high frequency and random nature, so that their presence is not indicated by air speed meters, manometers, or other velocity measuring devices involving inertia. Accordingly a need exists for methods of studying such turbulence both quantitatively and qualitatively.

Numerous schemes for meeting this need have been proposed and investigated heretofore, only one of which, the hot wire anemometer, satisfies at all well the aerodynamical requirements. This device, ostensibly simple and relatively satisfactory, consists of a fine wire heated electrically by current flow and subjected to the variable cooling induced by the velocity fluctuations in the moving air stream. The corresponding variations in voltage drop of the wire are amplified to measurable proportions for oscillographic study or direct meter indication.

Difficulties Inherent in Hot Wire Anemometer Scheme

Inherent in this scheme are 2 fundamental difficulties, compensation and calibration, both of which are surmountable but not without the introduction of some ambiguity into the results. Since ordinary turbulence has a frequency spectrum much like that of acoustic noise, compensation is essential because the hot wire response is much greater for low frequency velocity fluctuations than for those of high frequency. In order to obtain something approximating a faithful reproduction of turbulence a distorting circuit must be employed in the amplifying equipment, the characteristics of which are dictated by the various factors contributing to the "lag" of the wire. The lag characteristics of the wire are, in turn, determined from a theoretical analysis necessarily involving assumptions and approximations. Such procedure is a rational one and necessary; but, it is unfortunate that no standard turbulence exists nor has any velocity fluctuation thus far been devised whose characteristics, in magnitude and quality, are known without serious ambiguity to serve as an over-all check on the fidelity of the hot wire apparatus except for very low frequencies. Moreover, the fairly obvious test which may be made of compensation by passing through the wire a heat-

Full text of a paper recommended for publication by the A.I.E.E. committee on research, and scheduled for discussion at the A.I.E.E. Pacific Coast convention, Salt Lake City, Utah, Sept. 3–7, 1934. Manuscript submitted April 23, 1934; released for publication June 4, 1934. *Not published in pamphlet form.*
1. For all numbered references see list at end of paper.

ing current containing an alternating component of known frequency gives only a partial verification since conditions under which the wire operates for this measurement are not equivalent to those encountered in actual use as an anemometer. Then too, this compensation necessarily influences calibration, that is, affects the interpretation of amplifier output measurements in terms of actual or relative velocity fluctuation. The method of computing magnitudes of turbulence from hot wire observations is, of course, not relevant to the present paper. Significant, however, is the fact that compensation and calibration are both functions of average air speed, a circumstance which increases both the experimental work and the subsequent reduction of data.

These Difficulties Not Encountered in the Glow Discharge Anemometer

Thus, despite the many desirable attributes of the hot wire anemometer and the excellent work which it has made possible, the thermal lag of the wire introduces difficulties which have stimulated a search for other means of studying turbulence. This quest has led to a new electrical method employing as its sensitive element a minute glow discharge. Such an electrical discharge at atmospheric pressure is characterized principally by a cathode glow a few thousandths of a centimeter in length and potential of the order of 300 volts, and a positive column having a voltage gradient of approximately 1,500 volts per centimeter. The corresponding discharge current is in the range of from 10 to 30 ma. The total voltage of such a glow, about 400 volts, acted on by a transverse stream of air, was found to increase substantially with increasing air velocity, throughout a range in speed as great as that ordinarily employed in wind tunnel studies. Moreover, this glow is responsive to turbulence and gives results which are in excellent agreement with those obtained with the hot wire. A description of these results and the essential apparatus yielding them, together with a criticism of the glow discharge method of analyzing turbulence, form the substance of this presentation.

Apparatus of the Glow Discharge Anemometer

A few exploratory experiments served definitely to establish the essential fact that a glow discharge is sensitive to air velocity. Moreover, these qualitative tests indicated practical limits for the length of the glow and magnitude of the discharge current, which, together with aerodynamical requirements as to size and disposition of the discharge electrodes specified the essential apparatus and the electrical quantities involved.

A mounting of electrodes for practical work is shown in Fig. 1. The electrodes proper are silver-soldered to the supporting rods which are kept at proper spacing by the screw clamping device and terminate in an insulating block.

A more elaborate gap mounting employed to study the variation of glow voltage with length for several values of air velocity is indicated in Fig. 2. The illustration is self-explanatory, giving clearly the means of adjusting gap length as well as showing the section of glass rod which insulates one electrode from the rest of the assembly. The removable tapering tips which hold the electrode points make relatively simple a change of tip material.

The electrical circuit found to be most desirable appears in Fig. 3. A transformer and rectifier tube

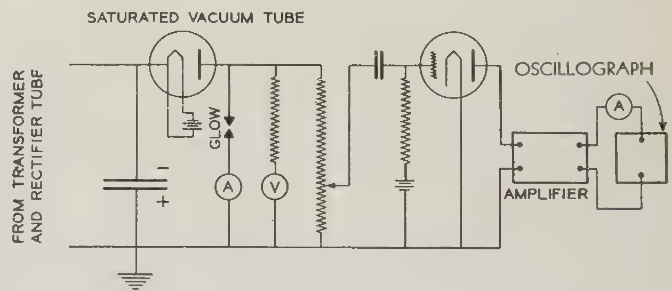
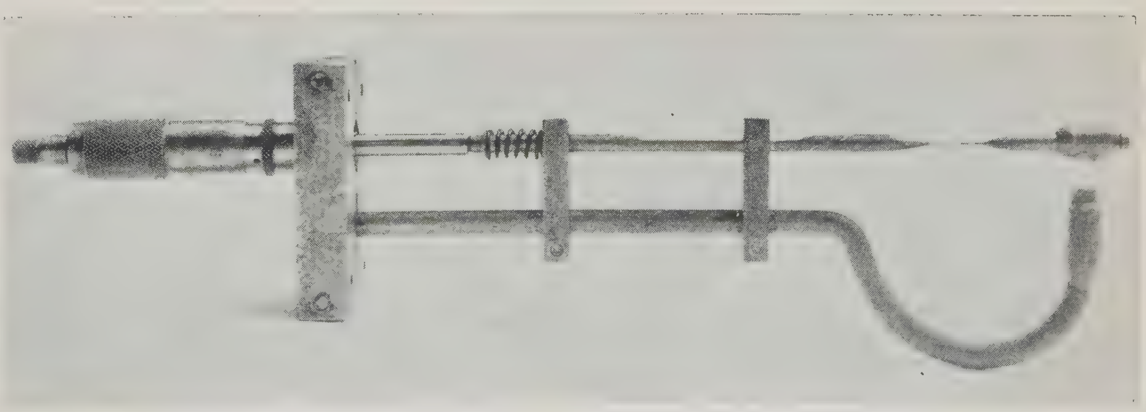


Fig. 1 (left). Glow anemometer mounting

Fig. 3 (right). Electrical circuit of glow and measuring apparatus

Fig. 2 (below). Glow anemometer with adjustable gap



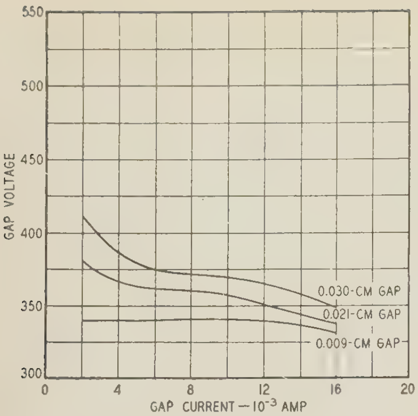


Fig. 4. Air velocity = 0

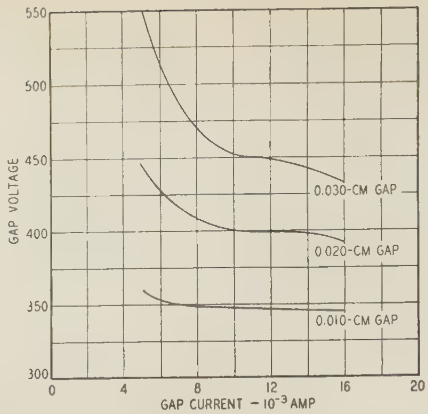


Fig. 5. Air velocity = 8 meters per second

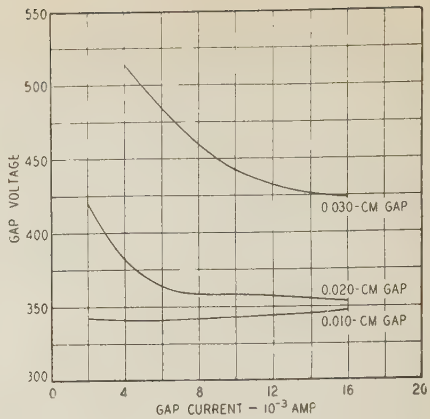


Fig. 6. Air velocity = 20 meters per second

Figs. 4–6. Glow voltage-current relationships

maintained the capacitor at a potential of approximately 5,000 volts. The glow discharge current was held constant by the saturated vacuum tube shown and was adjustable through filament current in a range of from zero to 50 ma. (This circuit is essentially that employed by Phillips Thomas in his studies on the microphonic properties of a glow discharge.[1]) The change in average voltage of the glow was measured with a microammeter having a series resistor of approximately 14 megohms and with a bucking circuit (not shown) set to give zero meter indication for the discharge operating in still air. Accordingly with the latter arrangement the increase in glow voltage produced by the air appears as a direct meter indication. An over-all calibration of this potential measuring circuit was effected by inserting in series with the glow voltage, by an obvious switching arrangement, a 45-volt battery which produced a meter deflection corresponding to this known increase in voltage. Such an arrangement was desirable inasmuch as frequent adjustment of the bucking circuit was necessitated by changes made in gap length or current.

Measurement of average air velocity was made with a standard pitot tube and precision manometer developed at the Guggenheim aeronautics laboratory of the California Institute of Technology, and when less accuracy was required, with a commercial air speed meter.

The foregoing equipment sufficed for an investigation of glow voltage as a function of air velocity, gap length, and discharge current. The fluctuations in voltage induced by turbulence in the moving air stream were transmitted through a coupling circuit and amplifier to an oscillograph and root-mean-square output meter. The coupling circuit, consisting of a capacitor and potentiometer, conformed to these important conditions: sufficient impedance to permit rapid fluctuation of glow voltage; adequate insulation in the capacitor to withstand the striking voltage of the gap and to prevent the running voltage of the glow from affecting the grid bias of the coupling tube; and appropriate shielding to minimize stray pick-up. The amplifier itself, following the coupling tube, was a commercial 2-stage unit. The over-all amplification, from the glow discharge input to the output meter, was adjusted, through the addition of filter circuits, to give very closely a uniform frequency response from 50 to 2,500 cycles.

Limits of Glow Current

The limits for glow current are empirical: too low a value leads to a stringy type of spark discharge at high voltage; too high a value leads to excessive heating and burning of the cathode, rendering impossible any reproducibility in curves of gap voltage as a function of air velocity. Moreover, for a certain limited range of current values, the gap voltage is nearly independent of current—a happy circumstance which makes small fluctuations in emission current of the control tube insignificant.

Details of Gap and Electrodes

The length of the discharge, or more precisely the length of the gap, since the former is indefinite due to spread of the cathode glow, is an important factor in this work as will be seen in the data to follow. Lengths ranging from 0.002 cm to 0.200 cm were tested and a useful range of from 0.010 cm to 0.025 cm was employed for most of the work with turbulent air flow. An extremely short gap is insensitive to air velocity while a long discharge is blown downstream into a bow shape having a greatly lengthened positive column with corresponding abnormally high voltage. Moreover, this "blowing back" gives an unstable type of discharge, apparently in a transition state between the spark and the glow types of conduction, which "sings" at a high audible frequency and therefore is worthless as a device for studying air velocity fluctuations. Accordingly, it will be noted that with the lengths of gap ordinarily employed, of the order of 0.015 cm, practically no positive column exists, only the characteristic cathode glows being visible.

For the investigation of the effect of discharge length, the adjustable gap, shown in Fig. 2, was used. The entire mounting with the exception of the cathode holder, was at anode or ground potential, while the cathode was insulated therefrom by a short length of glass rod rigidly gripped in metal ferrules. Various metals were used for electrodes: copper, brass, iron, steel, nichrome, nickel, silver, chromium, tungsten, platinum, and platinum-iri-

dium. All electrodes were approximately 0.15 cm in diameter with ends ground conically at about 20 deg taper. Of these various materials platinum, platinum-iridium, and tungsten were the most satisfactory, giving the minimum of difficulty from destruction of the points. Platinum gave a more consistently stable discharge as well as better reproducibility in data than did tungsten and therefore was used for the bulk of the tests.

In such a test device, the diameter of the electrodes should be comparable to the dimension of the glow itself in order that velocity, as measured, be definitely that of the stream flow and not the true velocity modified by the presence of bulky electrodes. Hence, only small diameter material may be used for cathode and anode with consequent small surface and cross section area for heat dissipation and conduction. Therefore, to minimize irregularities in behavior of the discharge due to heating of the electrodes a current value must be used which is as small as will give a satisfactory response of the gap over a particular velocity range.

Tests Without Turbulence Introduced

The first group of tests had as an object a study of the interdependence of glow voltage, glow current,

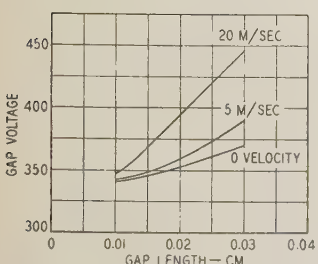


Fig. 7. Glow voltage as a function of gap length

Current = 10 ma
Air velocity = 0, 5, and 20 meters per second

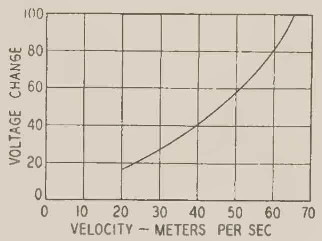


Fig. 8. Change of glow voltage with air velocity

Current = 14 ma

gap length, and air velocity, the air flow being turbulent to a negligible extent. The procedure was to measure glow voltage as a function of current for specific values of air velocity and particular settings of gap length. Typical results of these measurements are given in Figs. 4, 5, and 6. Glow voltage is plotted against current, each figure being for a designated air velocity and each curve corresponding to the gap length indicated. In order to avoid confusion only 3 gap settings are given.

The nature of these curves is in accord with that of a normal glow discharge. The extremely short gap gives a glow voltage virtually independent of gap current, except for high air velocity. Indeed, one may say that the short glow is almost wholly a cathode phenomenon, and only when the discharge is effectively lengthened by the transverse air motion, does it exhibit the negative resistance quality so characteristic of the typical glow discharge. The longer gap, however, gives rise to a discharge having the familiar hyperbolic characteristic for all air velocities including zero. Yet, considering all of the curves with a view to finding an optimum current value for air flow study, one sees that for the velocity range of these data 10 or 15 ma in the discharge gives an over-all minimum of voltage change due solely to current fluctuation.

Choosing, then, a particular value of current to be maintained in the discharge, curves may be derived from the preceding data which indicate the dependence of gap voltage on gap length, air velocity being an arbitrary parameter. Such curves, presented in Fig. 7, exhibit the essentially linear nature to be expected as the relationship between voltage and length of discharge, and suggest that the increase in glow voltage with velocity is due largely to a lengthening of the discharge.

Then, finally, from such data were obtained curves relating the essential quantities, voltage and air velocity. These curves, such as the one of Fig. 8 could be made to have either increasing or decreasing slope with higher air speed, giving sensitivity in either the low or the high velocity range by suitable choice of gap length and current.

These calibration curves indicate a voltage change of the order of volts per meter per second velocity increment, a response which is ample for investigating turbulence of quite small magnitude. Indeed, the sensitivity of the glow to turbulence, as predicted by such data, is approximately 100 times as great as that of the hot wire anemometer, substantially simplifying the amplifier problem. Accordingly it remained to demonstrate that the glow discharge responds faithfully to turbulence and to that only.

Tests on Response to Turbulence

That the glow really responds to turbulence was shown qualitatively in the wakes behind cylinders and flat plates where conditions are fairly well known from accepted theoretical and experimental aerodynamical research.[3,5] Moreover, the oscillographic representation and the amplifier output meter readings observed during any traverse of the air flow downstream from an obstruction, conformed beautifully with results of similar tests made in air and other fluids by various means. The glow anemometer gave no indication of turbulence in those portions of the flow known to be steady, thus eliminating the possibility of microphonic response, but it responded unquestionably to the velocity fluctuations in regions of disturbed flow, bringing out, in addition

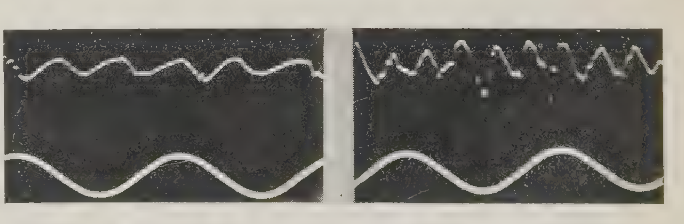


Fig. 9. Turbulence behind cylinder for 2 air velocities

Left, upper trace—9.9 meters per second velocity, frequency 133 cycles. Right, upper trace—16.3 meters per second velocity, frequency 220 cycles
Lower traces—50-cycle timing waves

to the usual random variations, the more or less regular sequence of vortices so characteristic of the wake behind a regular body. The oscillograms of Fig. 9 represent such a vortex sequence behind a cylinder for different air velocities, with a 50-cycle timing wave included to establish the frequency of the turbulence. These frequencies were found to agree with values computed from the vortex theory of von Kármán[3] which states that frequency is directly proportional to velocity and inversely proportional to the diameter of the cylinder. The factor of proportionality is 0.18 for any consistent set of units.[4]

Further confirmation of the response of the glow to turbulence came with simultaneous oscillograph records for hot wire and glow located at similar points in the 2-dimensional flow behind a cylinder.

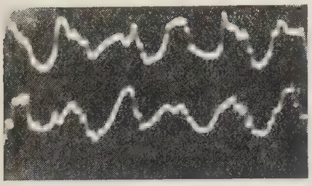


Fig. 10. Comparison between glow and compensated hot wire systems for measuring turbulence behind a cylinder

Upper trace. Hot wire scheme
Lower trace. Glow discharge scheme

The oscillograms of Fig. 10 show clearly that the glow response is as nearly like that of the compensated hot wire as the instantaneous velocities at 2 points in a turbulent fluid would compare. Moreover, simultaneous quantitative measurements of turbulence, root-mean-square velocity fluctuation divided by average air speed, gave good agreement between glow and hot wire methods.

The calibration of the glow anemometer for quantitative measurements of turbulence was achieved in a relatively simple way. Either mean-square or root-mean-square velocity fluctuation is a convenient quantity for theoretical consideration of turbulence, and either is conveniently metered in the amplifier output. Accordingly, if at a certain average speed, turbulence produced a particular root-mean-square output current, that same value of current was later caused to flow by impressing an adjustable alternating voltage at approximately 500 cycles across the terminals of the glow discharge. For example, suppose that 3 volts effective, 500 cycles, at the gap produced the same value of output current as the turbulence. A voltage fluctuation of 3 volts root-mean-square therefore must have been caused by air speed variation. A portion of the curve of gap voltage against average air speed establishes the value of the slope $\frac{\Delta e}{\Delta v}$ at the test velocity—only 1 or 2 points on either side being necessary—and leads at once to a value of root-mean-square velocity fluctuation. In short, the calibration as used was of the over-all type in which all essential data were taken at the time of the turbulence measurements.

Discussion of Results

The data which have been obtained with the glow anemometer demonstrate that such an electrical discharge is sensitive to air velocity in both the steady and turbulent states. Moreover, for the study of air turbulence this electrical method has certain definite advantages over the hot wire scheme, notably in calibration and simplicity of amplifying equipment. Yet, the glow itself has one notably outstanding defect which, fortunately, is more of a nuisance than an evil. Any such electrical discharge will inevitably result in some slow loss of electrode material, through sputtering and chemical modifications in the presence of air. And, as a consequence, a particular length of gap as used in this work will lengthen appreciably during the course of a run of 15 or 20 min duration, so that final data will not coincide with the original average calibration curve. Still, this difficulty is more apparent than real for 2 reasons. First, in turbulence studies made in the course of usual wind tunnel or other air flow work, ample opportunity exists for obtaining average voltage-speed data near the operating point at a time near enough to that of the turbulence measurement to give the characteristic slope. And, second, the slopes of 2 calibration curves corresponding to slightly different gap lengths are, for the same average air speed, practically identical. Consequently this defect in the glow anemometer is not serious, it merely prescribes a technique of measurement. And, indeed, the hot wire, because of accidental adherence of dust particles or due to other surface charges, has been found to be erratic in calibration from day to day.

One further critical comment on the glow anemometer is pertinent. The thermal time lag of the hot wire is of first importance in turbulence investigations. The glow, on the contrary, appears to have no lag in its response to air velocity change. The evidence which can be cited in support of this statement, however inadequate, must be considered in the absence of a satisfactory method of experimental verification, as previously discussed. Nothing in the mechanism of an atmospheric glow of the dimensions used could introduce a time lag significant in the frequency range of turbulence, for ion mobilities are adequately high.

Then, too, in the work which employed a glow as a microphone[1] it was found that a flat frequency response was approached as shorter gaps were employed, a fact which is significant when it is realized that for an anemometer a much shorter gap length was used than for a microphone. And, finally, the direct comparison of glow and compensated hot wire showed no indication of time lag in the glow discharge.

In conclusion, it may thus be stated that a new and interesting property of the atmospheric glow discharge—the variation of voltage with air velocity—has been shown to exist and that this property may be utilized in an anemometer for the study of turbulent air flow. Such an anemometer, the author believes, is a useful adjunct to the hot wire equipment, and, because of the essential ruggedness of the glow mounting, may be incorporated in a wind tunnel for routine measurements, an opinion which was encouraged largely by the consistent interest shown in this work by Dr. Theodor von

Kármán, director of the Guggenheim laboratory of aeronautics at the California Institute of Technology.

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Distance Relay Action During Oscillations

The behavior of distance relays during system oscillations is analyzed in this paper, and curves are presented for determining whether the oscillations are likely to cause relay operation. Different types of distance relays are considered and general methods of analyzing system conditions are discussed.

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OPERATING experience with directional distance relays has demonstrated their ability to clear short circuits rapidly and reliably. However, a few instances have been reported in which apparently a circuit breaker was opened when portions of the system were subjected to a power oscillation or lost synchronism because of a fault. Within recent years much study has been devoted to the effect of relay characteristics upon system stability and it now appears desirable to consider the converse, namely, the effect of an unstable system upon the relays protecting the unfaulted portions.

The term "unstable" is here used to denote any condition of operation during which the rotors of the connected synchronous apparatus do not maintain a substantially constant angular relationship with each other. Under this classification there can be 2 kinds of instability; (1) one is a continuous, unidirectional angular departure of one or more rotors with respect to the others which results in loss of synchronism, slip, or out-of-step operation; (2) the other is a fluctuating change of relative rotor positions, termed oscillating, swinging, or surging, which eventually will damp down to a condition of stable equilibrium.

There is some diversity of opinion as to whether or not distance relays should open any circuit breakers during out-of-step operation, some engineers believing that the essential separation should be performed manually or automatically at a predetermined point in conformity with the load conditions, and others caring little where it occurs, provided no load is left without a source of power.

On the other hand, opinion is nearly unanimous in preferring that under oscillating conditions no circuit breaker shall be opened by any protective relay. Since such an eventuality is within the bounds of possibility, this paper is presented to point out the procedure to be followed in determining whether distance relays in a particular location are in any danger of tripping unnecessarily during swings. Methods of avoiding such false operation are presented which may be used should a study show a need for remedial measures.

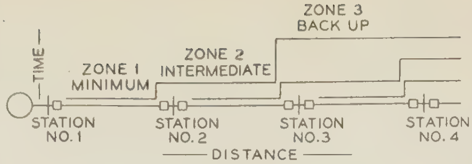
TYPES OF RELAYS AND THEIR CHARACTERISTICS

Two general types of directional distance relays are available, one using line reactance and the other line impedance as the measure of the distance to the point of fault. Both types have 3 distinct elements: (1) a directional unit; (2) an ohm unit or units consisting, in the reactance relay, of one or more reactance measuring devices, and in the impedance relay of several impedance measuring devices corresponding to the number of steps in the relay; and (3) a timing unit. In the impedance relay the indicated line impedance is obtained by comparing the magnitude of the voltage with that of the current. In the reactance relay the comparison is made between the current and the inductive component of the voltage.

Both types of these relays have a "step characteristic" giving definite operating times for different fault locations, as shown in Fig. 1. A fault in zone 1 (often called instantaneous zone), which covers approximately 80 per cent of the line distance to relay station 2, is cleared in minimum time. A fault in zone 2, which covers the last 20 per cent of the line to relay station 2 and something less than 80 per cent of the line distance to station 3, is cleared in intermediate time, and a fault in zone 3 is cleared in back-up time (so called because no relay should ever operate in this time unless some other device has failed to operate correctly). In considering

Full text of a paper recommended for publication by the A.I.E.E. committee on power transmission and distribution, and discussed at the A.I.E.E. North Eastern District meeting, Worcester, Mass., May 16–18, 1934, and also scheduled for discussion at the A.I.E.E. Pacific Coast convention, Salt Lake City, Utah, Sept. 3–7, 1934. Manuscript submitted Feb. 27, 1934; released for publication March 19, 1934. *Not published in pamphlet form.*

Fig. 1. Time-distance characteristics of directional distance relay



distance relay performance during power swings, these operating zones are important and subsequently will be designated as instantaneous, intermediate, and back-up zones.

Directional distance relays are generally installed to take care of 3-phase, line-to-line, and double-line-to-ground faults. A few installations have been made for line-to-ground faults, but since ground distance relays are not affected by balanced 3-phase power swings, only line relaying is here considered.

Origin and Nature of Instability

The nature of short circuits and their effect upon distance relays has been amply treated in published literature. Methods of calculating system oscillations have also been described in previous papers but it is believed that a brief review of the origin and nature of instability will facilitate the study of its effect upon distance relays. In a loaded stable system all synchronous apparatus rotates at a constant electrical speed with certain constant angular displacements between the generated voltages, since in a synchronous system energy is transferred by an angular separation of voltages. (See Fig. 2.) Two opposing torques act upon the rotor of each machine, a mechanical shaft torque and an electrical stator torque. In equilibrium these must be exactly equal and opposite at all times (as at 0, curve A, Fig. 2). When either changes, the affected rotor will start to move at a different angular velocity from the rest of the system in an endeavor to find some new angle which again equates the torques, but while so moving its mass has been acted upon by the torque difference, and stored energy of motion away from system angular velocity has been imparted to it. For example, consider a motor connected to a large system having a shaft torque T_1 in Fig. 2. Assume the load to change suddenly so that the mechanical torque is T_2. The generated or excitation voltage of the motor has the angle α with respect to the system voltage which only results in an electrical torque of T_1. The rotor accordingly begins to slow down and increase the angle, thereby raising the electrical torque, which varies as the sine of the angle. When the voltages are separated by angle β (point 2) the 2 torques are equal but the rotor has put out more energy than it received and is traveling at a speed corresponding to a different frequency from that of the system. It does not stop at angle β but continues to drop behind the system, now having more input than output. It will continue to some angle γ (point 4) until the previous excess output is canceled by the excess input, at which instant it rotates at system frequency, but with more input than output. The process is now reversed and the rotor advances, changing the electrical torque along the curve from 4 to 2 toward 0, after which the entire cycle is repeated and would continue indefinitely if it were not for damping factors which reduce the amplitude of each oscillation, until finally equilibrium is reached at point 2.

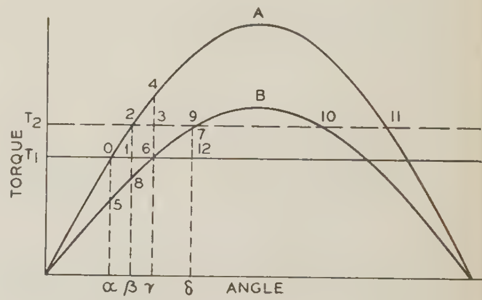
A sudden change in electrical torque produces an analogous but opposite action. Assume the same motor to have a mechanical torque of T_1 and to be operating with angle α at point 0 on curve A. Let the electrical torque angle characteristic of the system and motor suddenly change to curve B. The rotor is still at angle α but the input is less than the output as at point 5. Again, the rotor drops back in angle to δ (point 7) and oscillates between 5 and 7. Thus, a sudden reduction in electrical torque initiates the same kind of phenomenon as a sudden increase in mechanical torque.

Example of Unstable Operation

In both of the examples given, the motor eventually would become stable and continue to operate in synchronism with the system. Had the mechanical load in the last example been T_2 originally, a different result would be obtained when the torque angle characteristic is suddenly changed from curve A to curve B. In this case the rotor would start at angle β (point 2) and the torque would drop to point 8. The rotor would slow down, increase the angle and input along curve B but when it reaches point 10 there would still be an excess of energy output over input so that it would continue to drop back. After passing point 10 the input drops below the output and the motor rapidly falls off in speed. Eventually, it will stop entirely or perhaps run as an induction motor at some slip below system frequency. In either event it is definitely out of step with the rest of the system. It has been proved that the final result of a sudden torque change will be determined by the available area lying above the mechanical torque line and within the electrical torque angle curve upon which the system happens to be operating. (See reference 2 in list at end of paper.) In the first example, the area 0, 1, 2 is equaled by area 2, 3, 4, and there is still an area 4, 3, 11 remaining in which the input exceeds the output and the rotor velocity may be stopped. Similarly area 6, 12, 7 equals 0, 5, 6 and there is more available if needed. In the last example, however, area 9–10 does not equal 2, 8, 9, and the machine loses synchronism.

Fig. 2. Torque-angle characteristic of a synchronous system

A and *B*—electrical torque-angle characteristic T_1 and T_2—mechanical torque



Causes of Sudden Changes

Sudden changes in electrical torque will be caused by short circuits and switching operations. Mechanical changes arise from poor synchronizing or suddenly applied loads. The result is invariably either a new stable condition or loss of synchronism by one or more machines or groups of machines. During the unstable period the current and voltage rise and fall alternately and oppositely and the voltage at any given instant is different in magnitude and phase position at different points on the system.

Vector Relations

Consider a simple loaded system comprised of a generator and motor with interconnecting lines between them. When operating stably, or at some particular instant during instability, the vector relations are as shown in Fig. 3. E_1 represents the internal voltage of the generator and may be either the excitation voltage or the voltage back of transient reactance, depending upon whether steady or transient conditions are under consideration. E_2 is the corresponding motor voltage, which normally would be nearly equal to E_1, but which is enlarged in Fig. 3 to show more clearly the distinction between the electrical and impedance centers. The total angle between generator and motor voltages is called displacement angle. At some point in the system, the voltage will be a minimum, and this point is referred to as the electrical center of the system. At the same or some other point the current and voltage are in phase with each other and this is denoted as the unity power factor point. When the excitation voltage of the generator and motor are equal and the system consists of reactance only, both of these points coincide with the impedance center, which is one-half of the total system reactance away from either end. If the system contains some resistance the electrical center still coincides with the impedance center but the unity power factor point is a fixed angle φ on the generator side of the electrical center, the angle φ being 90 deg $- \tan^{-1}\dfrac{X}{R}$ where X and R are total reactance and resistance including generator, system, and motor. If the excitation voltages are unequal neither point falls at the impedance center and both vary their position with the angle between generator and motor voltages, but the unity power factor point remains the same angle ahead of the electrical center at all times.

Study of a Representative System

The electrical characteristics of a synchronous system can probably best be shown by giving the results of a study of a representative system. The system for this study consisted of 2 equivalent machines, a generator, and a motor with a single reactance tie between them. The machines had equal excitations and normal power occurred at a system angle of 45 deg. Synchronizing power and the magnitude and phase relations of the current and voltage at 3 relay stations on the line between the equivalent machines were determined. Relay station 1 was located midway between the equivalent generator and the electrical center, relay station 2 at the electrical center, and relay station 3 at one-quarter of the distance between the electrical center and the equivalent motor.

The variation of the system electrical characteristics as a function of the displacement angle is shown in Fig. 4. Synchronizing power varies proportionally as the sine of the displacement angle; line current as the sine of half this angle. The voltage and angle between current and voltage at the various relay stations are functions not only of the displacement angle but also of the location of the relay station with respect to the electrical center of the system, the lowest voltage occurring at the relay station nearest the electrical center of the system.

The time variation of these electrical quantities depends upon the rate of change of the displacement angle. In an actual system, the rate of change of the displacement angle is not uniform, the angle increasing slowly at first as the rotating machines start to accelerate and later changing more rapidly if the machines go out of step.

In Fig. 5 are shown the curves of Fig. 4 replotted to a time scale which is representative of an unstable system. As the rotating machines go out of synchronism, the line current increases with the displacement angle and becomes a maximum at a displacement angle of 180 deg. The voltage at the several relay stations decreases as the displacement angle increases and the angle between the current and voltage at these stations increases. At 180-deg total displacement angle the voltage at the electrical center of the system is zero and the current is a

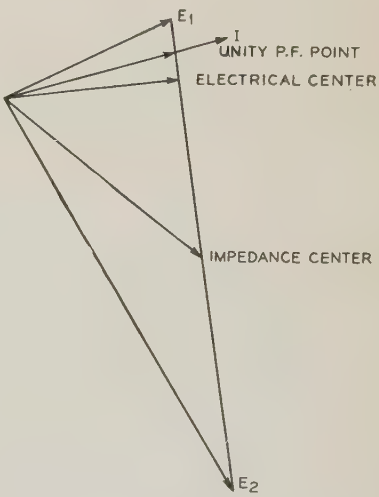
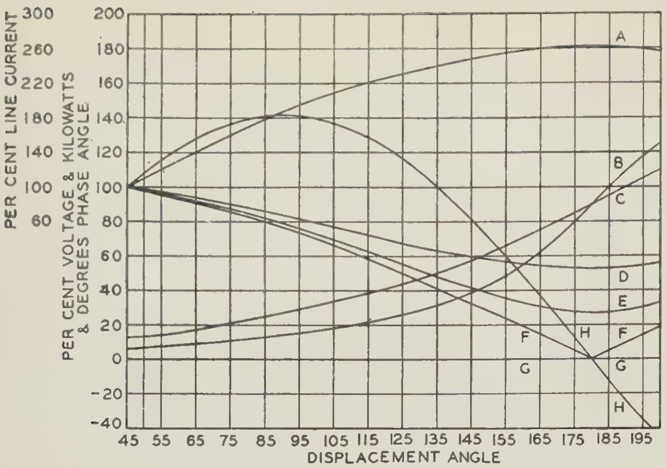
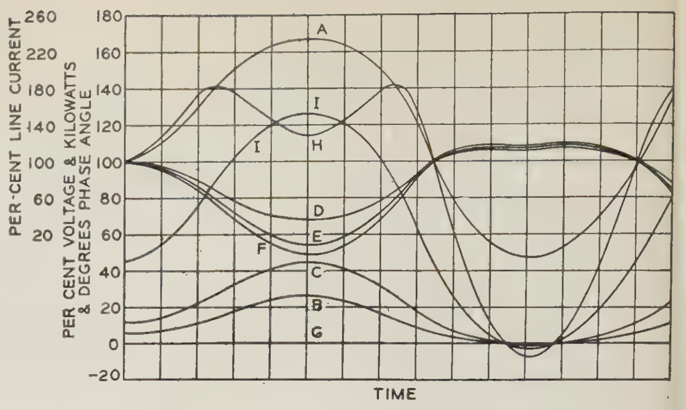


Fig. 3. Vector relations of a 2-machine synchronous system

maximum, a condition that appears to the other relay stations as a 3-phase fault at the electrical center of the system.

When a system swings but does not go out of synchronism, the line current reaches a maximum and the voltages at the relay stations become a minimum at the maximum angle of swing. While it is theoretically possible for a system to swing to an angle of 179 deg, the practical limit in most cases





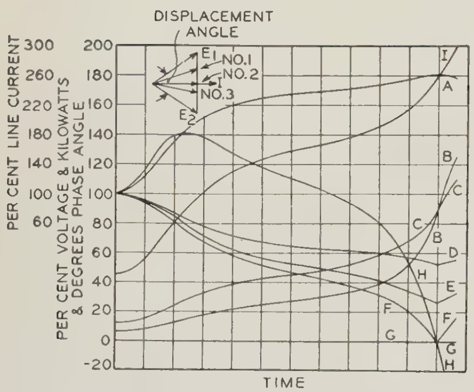


Fig. 4 (left, above). Variation of system electrical characteristics as a function of displacement angle

Fig. 5 (left). Variation of electrical characteristics of an unstable system as a function of time

Fig. 6 (right, above). Variation of electrical characteristics of an oscillating system as a function of time

A. Line current
B. Angle current leads voltage No. 3
C. Angle current lags voltage No. 1
D. Voltage at relay station No. 1
E. Voltage at relay station No. 3
F. Voltage at relay station No. 2
G. Angle of current with voltage No. 2
H. Kilowatts
I. Displacement angle

probably does not greatly exceed 120 deg, with maintained synchronism. The current and voltage conditions at the 3 relay stations during a power swing which ultimately resumes stability are shown in Fig. 6. These curves indicate that during such a power swing the line current may increase and the relay station voltages may dip sufficiently to give tripping indications to the relays at the stations, and undesirable relay operations may occur unless some provision is made to prevent them.

Action of Distance Relays

Since distance relays utilize the electrical dimensions of the system at their location, they are presented with a very difficult problem of discrimination in attempting to distinguish between faults, swings, and loss of synchronism. In an impedance relay the discrimination between normal and abnormal conditions is usually performed by the impedance devices. In a reactance relay it is performed chiefly by a starting, fault detecting unit rather than by the reactance elements, because, except during faults, reactance elements as usually connected will indicate the distance to the unity power factor point of the system and would operate in a time depending upon the location of the relay with respect to this point, unless there is a change in the number of parallel circuits between the relay location and the unity power factor point. The reactance elements are of some benefit in preventing undesirable tripping by relays located at some distance from the unity power factor point. Hence a study of the susceptibility of directional distance relays must include the starting units as well as the distance measuring elements.

An impedance relay, except during fault conditions, indicates any value from infinity down to the impedance between its location and the electrical center of the system, depending upon the total displacement angle between machines and the location of the relay with respect to the electrical center.

In a pure reactance system at 180-deg displacement angle, impedance and reactance relays indicate alike, but at stable system angles, impedance relays measure something greater than the distance to the electrical center.

At first glance it would appear that a swing of sufficient amplitude to operate either reactance or impedance relays would result in clearing only the section containing the electrical center, because both the reactance and impedance measurements are a minimum at its ends; but unfortunately this does not invariably hold true. As will be brought out later, the starting units of reactance relays remote from the center may operate earlier in the swing than those nearer the center. The ohm units will indicate intermediate or back-up time, but as this expires and the relay is about to trip, the starting unit of the relay on the line containing the unity power factor point may operate and its ohm unit indicate instantaneous tripping so that 2 circuit breakers open simultaneously. With the impedance type, the relay nearest the electrical center will have the lowest indicated impedance in any portion of the cycle but those adjacent to it may have but little more and may have a higher ohmic setting because

of different line lengths. As with the reactance relays, the gradually decreasing ohmic indication may start to trip some breaker in back-up or intermediate time, but as the timer completes its travel the instantaneous element of some other relay operates also. Unless the starting unit, or instantaneous impedance element, of the relay nearest the center operates there will be a time delay before the relay trips, and if the swing is rapid the indicated ohms may rise and cause the relay to reset without completing its contact circuit. Hence, the prediction of the behavior of distance relays during system oscillations or out-of-step conditions requires a study of both relay and system characteristics.

Characteristics of Relay Starting Units

The type *GAX* relay is a single-phase 3-step directional distance relay operating on the reactance principle. The type *GCX* relay is similar in principle, but incorporating certain mechanical refinements.

The operating torque of the starting unit of the type *GAX* reactance relay is approximately *EI* sine (θ + 15 deg) with E^2 restraint. The characteristics of the starting unit of the type *GCX* reactance relay deviate only slightly from those of the type *GAX* relay, the principal difference being a means for changing the sensitivity to several values of minimum operating current. These values are approximately 8, 12, and 16 amp at the angle of maximum torque and 100 per cent voltage. At the reduced voltages existing during faults the minimum operating current also goes down, the actual value depending upon the type of short circuit and angle of lag of the fault current. Thus the tap values are by no means the fault current required to operate the relays. These starting units will have a maximum tendency to operate at various distances from the electrical center depending upon the total angle between the machines. Relays having double current coils, delta connected current transformers, or quadrature connection and located near the electrical center would not operate since the sine (θ + 15 deg) is small, causing a high pick-up.

The impedance relay has the greatest tendency to operate when located at the electrical center for this is the place of lowest voltage on the system and the current is probably as high as anywhere else.

Curves of Relay Susceptibility

The likelihood of false operation of either the impedance or reactance relay during stable power swings depends upon: (1) the location of the relay station with respect to the electrical center of the system; (2) the maximum angle of the swing; and (3) the sensitivity of the fault detecting elements. In order to enable users to determine the possibility of an incorrect relay operation arising from system oscillations, a set of curves has been prepared to show the relative susceptibility of these relays to power swings. In the preparation of these, certain simplifying assumptions have been made which, nevertheless, do not detract from their usefulness. It is assumed that the relays under study are located on the tie between portions of a system and that there is an interchange of power over this tie. The system is then considered as 2 machines, an equivalent generator and a motor connected through the tie, each having the combined impedance of the group up to the relay bus at its end of the tie. This method of grouping and the calculation of the swing resulting from a shock such as a short circuit has been described in previous papers. The machines are assumed to have equal excitation and the tie is assumed to be pure reactance. The starting units of the reactance relays are assumed to have maximum torque when the current lags the voltage by 90 deg. However, these curves also apply to relays which have maximum torque at some other angle when it coincides with the natural angle of the system. (The term natural angle of the system refers to the angle whose tangent is the total reactance from end to end including the equivalent machines, divided by the total resistance.) Various maximum displacement angles have been assumed and the operating characteristics of the relays when located at and away from the electrical center have been plotted.

In order to employ the curves it becomes necessary to reduce the system to an equivalent 2 machine group and either calculate or assume a maximum stable angle of swing. If the maximum load over the tie is known the maximum angle with ultimate stability may be assumed as the same number of degrees above 90 deg that the stable operating angle is below 90 deg, *e. g.*, if the system operates with 60 deg between voltages at the maximum load, the maximum displacement angle is 120 deg. This does not mean that the system will necessarily swing to the maximum angle after every disturbance but it cannot go beyond this angle and retain synchronism. A large amount of labor is saved if the angle is assumed and the relay performance found to be satisfactory should this angle be reached. Naturally

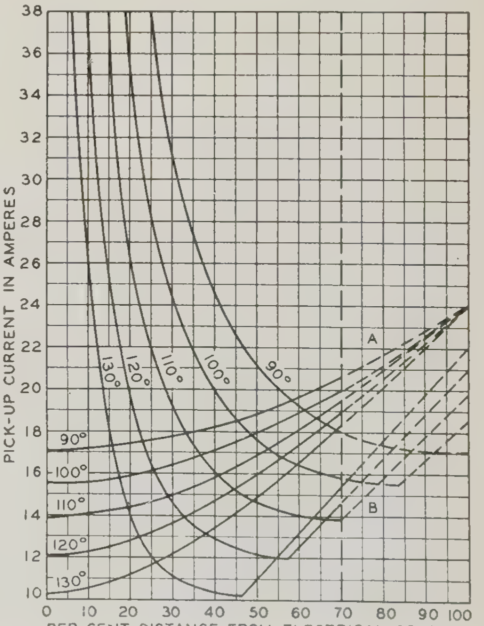


Fig. 7. Characteristics of 12-amp tap of type GCX relay starting unit with 4.8-ohm "ohm unit" and 4.8-ohm impedance relay for several displacement angles

A. Impedance relay
B. Reactance relay, type GCX

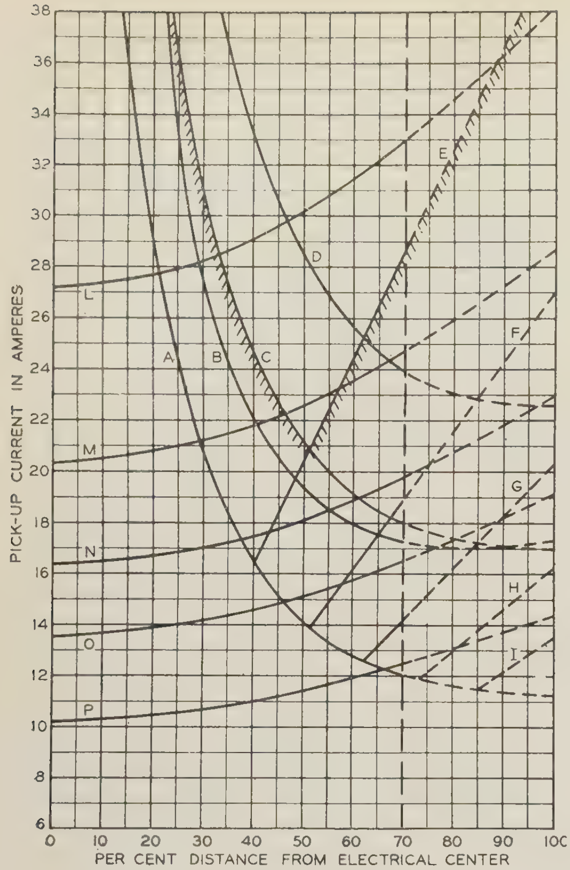


Fig. 8. Displacement angle 90 deg

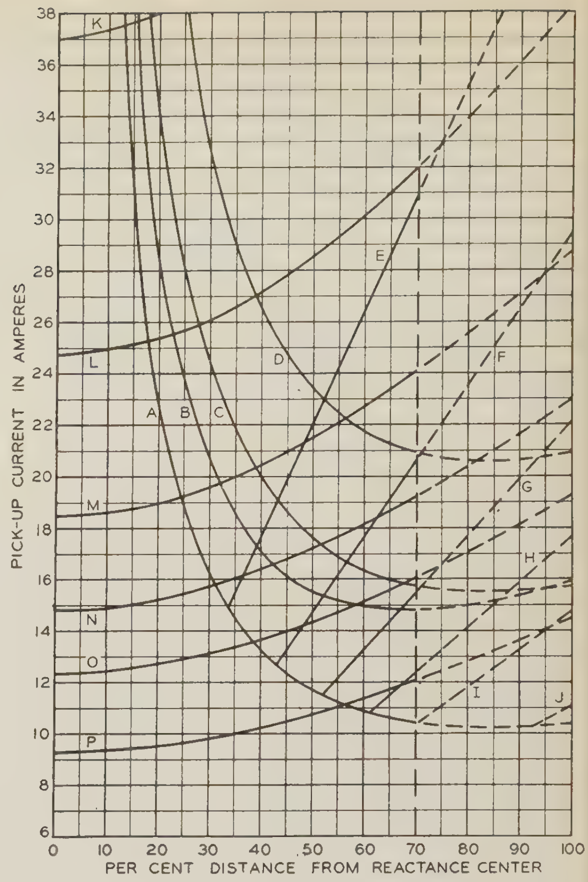


Fig. 9. Displacement angle 100 deg

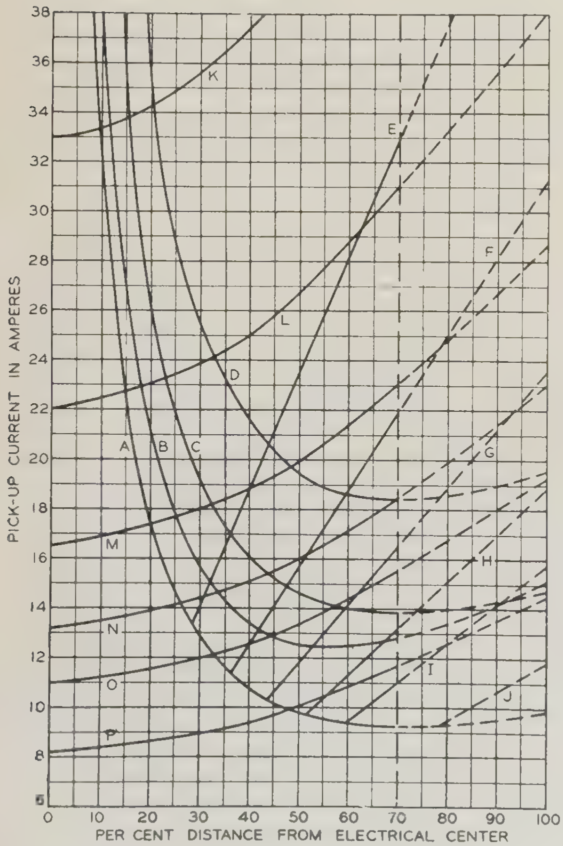


Fig. 10. Displacement angle 110 deg

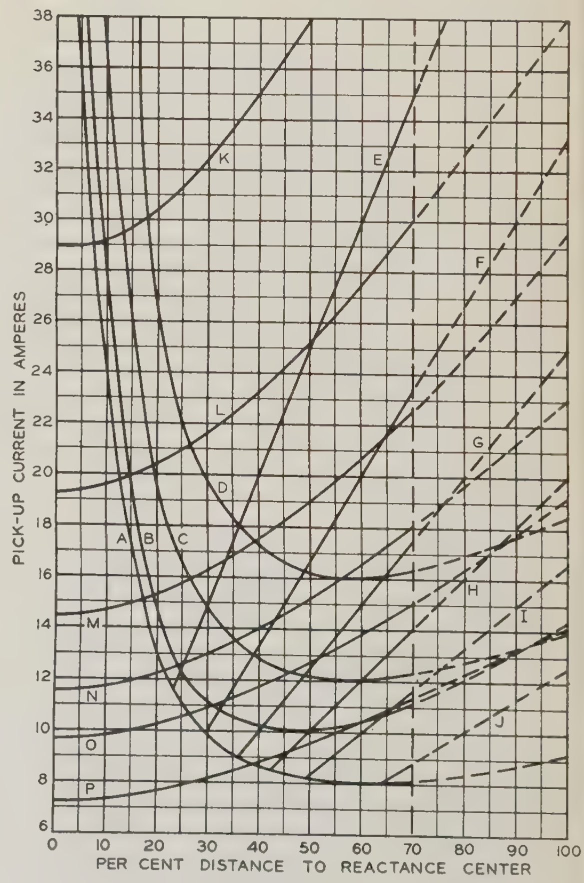


Fig. 11. Displacement angle 120 deg

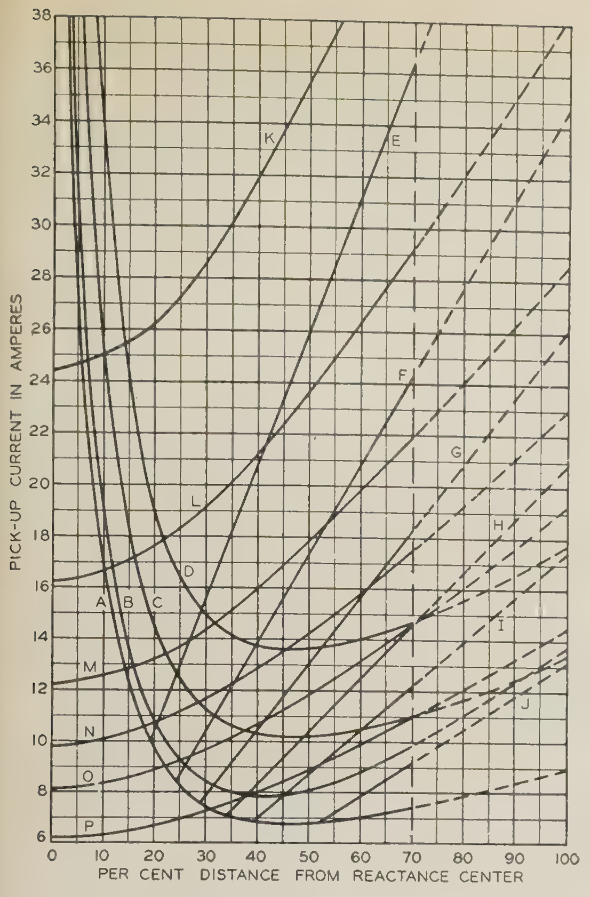


Fig. 12. Displacement angle 130 deg

Figs. 8–12. Characteristics of directional distance relays

A. Starting unit of type GCX relay, 8-amp tap
B. Starting unit of type GAX, relay standard
C. Starting unit of type GCX relay, 12-amp tap
D. Starting unit of type GCX relay, 16-amp tap
E. Reactance ohm unit, 2-ohm setting
F. Reactance ohm unit, 3-ohm setting
G. Reactance ohm unit, 4-ohm setting
H. Reactance ohm unit, 5-ohm setting
I. Reactance ohm unit, 6-ohm setting
J. Reactance ohm unit, 8-ohm setting
K. Impedance relay, 2-ohm setting
L. Impedance relay, 3-ohm setting
M. Impedance relay, 4-ohm setting
N. Impedance relay, 5-ohm setting
O. Impedance relay, 6-ohm setting
P. Impedance relay, 8-ohm setting

if it appears that the relays will operate to trip at the assumed angle, it becomes necessary to calculate the maximum angle for the assumed load, type of fault, and fault duration in order to determine whether the relays will be stable or not under actual operating conditions. Methods for doing so have already been published.

In addition to determining the maximum displacement angle, the secondary current in the relays must be found. This is a function of the system impedance, the maximum angle, the current transformer ratio, and the relay connection, and may be readily calculated. It is also necessary to express the location of the relay station in the system as a percentage of the total impedance from the electrical center to the end. With these factors established, the accompanying curves may be used to ascertain the stability of distance relays at any particular location for the specified disturbance and subsequent system oscillations.

Comparison of Relays

A comparison between the characteristics of the 12-amp tap of the type *GCX* relay starting unit and an impedance relay of equal sensitivity when located at the electrical center is shown in Fig. 7. The ohmic setting of the impedance relay was selected by dividing the voltage at the electrical center of the system for any given displacement angle by the minimum current required to operate the type *GCX* relay under the same conditions at its most sensitive location. Each curve is drawn for a different displacement angle and shows the minimum operating current as a function of the location of the relay station with respect to the electrical center. The curves demonstrate that for the 2 types of relays the point of maximum sensitivity varies both with location and displacement angle and the variations are entirely different. For example, with a total angle of 110-deg displacement, the impedance relays having the same minimum operating current as the type *GCX* starting unit will be more sensitive for any location within 40 per cent of the electrical center while the type *GCX* starting unit will be more sensitive in the end zone. This comparison is given because any system may have both types of relays in service and each type may be in the region where it is most likely to give an unwanted operation.

In Fig. 7 and all of the succeeding curves, a line has been drawn at 70 per cent of the distance between the electrical center and end to indicate the probable boundary of any relay station locations, the remaining 30 per cent representing transformer and machine impedance.

Two types of reactance relays with impedance relays set for 2, 3, 4, 5, 6, and 8 ohms are compared in Figs. 8 to 12. These are more useful for general use, since it is possible to interpolate to obtain the characteristic of any ohmic setting of impedance relay. Each is drawn for a different displacement angle and represents as static, conditions that in reality are changing with time. It does not necessarily follow that a relay will close its contacts even though an angle is reached which, if maintained, would cause it to do so, because the system may return to a smaller angle before the relay had time to operate. For example, the 12-amp type *GCX* relay starting unit with the instantaneous ohm unit set for 2 ohms can trip in instantaneous time only if the pick-up current at a given relay station lies within the "V" formed by the crossing of the starting and 2-ohm unit characteristic as shown by the shaded portion of the curves in Fig. 8. Should the current be sufficient to pick up the starting unit but lie outside of this shaded area, the relay would trip after a time delay depending upon the ohmic settings of the intermediate and back-up zones, and providing that the swing current remained above the pick-up value for a time long enough to allow the relay to complete its timing.

All of these curves indicate that under certain conditions it is possible for distance relays to operate during power swings unless provision is made to prevent such operation. The impedance relay is more sensitive to swings when located in a relay station at or near the electrical center of the system while the reactance relays have their maximum sensitivity at a point away from the electrical center, the location varying with the maximum angle of swing.

Location of Electrical Center

The location of the electrical center of a system depends upon the number of lines in service and the connected apparatus. As system connections change from time to time, so will the electrical center change, and a relay station located a considerable distance away from the center for one system set-up may be near the electrical center with another set of connections. A study of any given relay installation should utilize the particular one of the usual operating conditions which is most unfavorable to the relay.

Distinguishing Faults From Swings

Having determined that there is a possibility of incorrect operation, and bearing in mind that directional distance relays should operate correctly for faults and should not operate for swings, it is fitting to examine what preventive measures may be taken. In order to prevent undesirable relay operations during power swings, in installations where they would otherwise occur, some means should be provided for distinguishing between faults and swings. When the faults and oscillations do not result in identical current, voltage, and power factor relationships, a change in current transformer ratio or tap setting may enable the relays to discriminate between them. A fault suddenly applies an active and reactive load to a system and in effect increases the impedance of the tie between the machines, with a resultant reduction of synchronizing power. On the other hand, it requires an appreciable time for a power swing to take place, and unlike a fault, the synchronizing power increases with the system angle up to an angle of 90 deg. Thus, there are 2 characteristics by which swings can be distinguished from faults: (1) synchronizing power; and (2) time.

It has been suggested that a true power relay could be used to block distance relays against tripping during power swings. To use such a power relay it should be set low enough to block for all power swings, and high enough so that there would be no danger of blocking on high resistance faults.

An arcing fault introduces resistance which varies with the arc length and changes the current, voltage, power, and power factor, and may bring these to the same value they have during a swing. An arc usually starts over an insulator string and in the course of time is stretched by wind or convection air currents. Since all faults should persist no longer than the intermediate time setting of the distance relays, the maximum arc length is determined by this setting and wind velocity. Although arcs of such length make the electrical quantities coincide with those existing in some portion of a swing, the oscillation takes much longer than the arc to reach these conditions. Thus by providing some blocking means and delaying its action until after the expiration of intermediate time, the relays will clear faults and will not trip during swings.

Separating Unstable Portions of a System

When a fault results in loss of synchronism the tie between the elements out of step must be opened to avoid the severe disturbances caused by such operation. There is little or no chance of regaining synchronism unless action of some sort is taken to bring the electrical and mechanical torques acting upon the machine into closer agreement and as this takes time it is usually considered better to effect a quick separation and resynchronize. Some system operators who have experienced instability plan to minimize its effect by prearranging for each operating condition the circuit breakers which shall be opened manually when instability occurs. The point of separation is so chosen that the generation and load in each section are roughly equal so that there is no great frequency change when the tie is opened. In other instances, where synchronous condensers have been the offenders, means have been provided for taking them off the line automatically, the loss of their capacity causing less distress than operation out of step.

The most satisfactory automatic method of separating unstable portions of a system would seem to be the use of an out-of-step relay especially designed for the purpose. Relays operating upon this principle may be installed at the point where separation is desired, or if this changes with system operation, several may be installed and the proper one placed in service manually for each particular operating set-up.

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Reignition of an Arc at Low Pressures

An investigation of factors influencing the reignition potential of an alternating current arc at low pressure is reported in this paper. The investigation was undertaken to determine if such data could throw more light on the transition from a glow discharge to an arc. The results are consistent with a theory proposed previously by one of the authors.

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RESULTS of a study of the factors influencing the reignition potential of an alternating current arc at low pressures are presented in this paper. The data were obtained from oscillograms of arcs at different currents, between electrodes of different materials in air at pressures ranging from 2 cm of mercury to atmospheric pressure, and for a gap setting of one millimeter.

At low current densities and at low pressures the reignition potentials using electrodes of carbon, copper, and graphite were approximately the same, proportional to the pressure, and lower than the sparking potential. At low pressures a high reignition potential is necessary to establish the arc even when the electrodes are carbon. At higher pressures and at higher current densities the reignition potential of carbon and graphite decreased with increase in pressure; no such decrease was found for copper electrodes. Impurities having a low work function decreased the reignition potential markedly. Conditions favoring high temperature of the electrodes also tended to decrease the reignition potential.

The experimental results are consistent with the theory that the transition from a glow discharge to an arc is due to the establishment of a high positive space charge at the surface of the cathode producing an electric field of high intensity.

General

Todd and Browne[1] have shown that the potential required to restrike an alternating current arc when the current reverses is low and of the order of the burning potential at atmospheric pressure, providing the electrodes are of carbon or tungsten. However, if the electrodes are of copper, brass, or other materials that cannot exist in the solid state at very high temperatures, the potential necessary to restrike the arc is very high compared to the burning potential. It is well known that in order to supply sufficient thermions to yield the large current densities found in the region of the cathode spot that a temperature exceeding 3,000 deg K is necessary. Both carbon and tungsten are solid at this temperature, and it is extremely probable that with these materials both electrodes of an alternating current arc are at a sufficiently high temperature to furnish all the electrons necessary for carrying the arc current by thermionic emission.

With electrodes of material that is not solid at these high temperatures, the thermionic current is so low that it is necessary to postulate some other mechanism of producing the large electron current that exists in the region of the cathode spot. In the cases where the electrodes cannot exist at very high temperatures, the most generally accepted theory of the cathode drop is that the electrons are drawn out from the cathode by the extremely high intensity electric fields that exist there. The intensity of these electric fields is of the order of 10^6 volts per centimeter.[6] When the current in an alternating current arc reverses, it is necessary to produce an electric field of very high intensity at the surface of the electrode that was formerly the anode. In order to do this it is assumed that a glow discharge first forms with its relatively high cathode drop, extending over a relatively large distance. As the current in this discharge increases, the magnitude of the cathode drop increases and at the same time the region over which the cathode drop exists decreases, both of these effects producing an increase in the strength of the electric field existing at the cathode. At some critical value the large cathode drop of the glow discharge collapses into the low cathode drop of the arc which, however, extends over a very small region. Transition from a glow to an arc occurs very rapidly if the current is high, but it occurs at every reversal of the current, and a relatively high restriking potential is necessary if the electrode material is not a solid at a very high temperature.

The present study was undertaken to determine if data obtained at low pressures could throw more light on the transition from a glow discharge to an arc.

Description of Apparatus

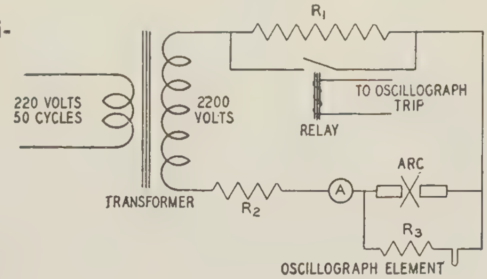
The circuit used is shown in Fig. 1. Resistance R_1 is a high resistance which, when the circuit is energized, will prevent the arc from striking. The relay, which short circuits R_1, operates after the oscillograph has recorded approximately one cycle of the impressed voltage. Resistance R_2 is used to adjust the arc current, which is measured by the ammeter A. Resistance R_3 determines the amplitude of the swing of the oscillograph element. All these resistances are water resistors.

Full text of a paper recommended for publication by the A.I.E.E. committee on research, and scheduled for discussion at the A.I.E.E. Pacific Coast convention, Salt Lake City, Utah, Sept. 3–7, 1934. Manuscript submitted June 5, 1933; released for publication Feb. 20, 1934. *Not published in pamphlet form.*

1. See bibliography at end of paper for all numbered references.

In all cases the arc occurred between the plane end surfaces of cylindrical electrodes 0.64 cm in diameter. The distance between the electrodes always was adjusted to 1 mm. The arc was allowed to burn only long enough to complete the oscillogram, and frequent adjustments of the gap were made to insure the desired separation of the electrodes. The electrodes and their holders were mounted in a bell jar which was connected to vacuum pumps and gauges by

Fig. 1. Experimental circuit



means of which the pressure was adjusted to the desired value prior to striking the arc. In the pressure range covered, no increase in pressure was observed after striking the arc. No other gas than air was used. Power was supplied to the circuit by the regular 50-cycle mains.

Experimental Results

The reignition potential is taken to be the maximum voltage reached prior to the restriking of the arc. In general, this voltage is not constant, but varies from cycle to cycle; and in the case of carbon electrodes the variation of the reignition potential in a single oscillogram might be as high as 50 per cent. When both electrodes were copper or very pure graphite the variation was not so great and was less than when one electrode was copper and one carbon. The most consistent results were obtained when both electrodes were pure graphite, in which the variation was less than 5 per cent (see Fig. 2). There was no consistent variation with time or *average* temperature of the electrodes. All data given were obtained from about 400 oscillograms and each point is the average of at least 7 measurements.

Figures 2 and 3 are typical oscillograms representing the drop in potential across an arc between graphite electrodes for 8 values of air pressure. The rms value of the current for each of these was kept constant at 1.5 amp. Figure 2 is an oscillogram showing the voltage drop across the gap as a function of time for low pressures. It may be noted that the voltage rises before the current reverses, to a value approximately equal to that of the cathode drop of the normal glow discharge in each case recorded here. At the time corresponding to point A the relay short circuiting the resistance R_1 was closed, starting the arc. At a pressure of 1 cm of mercury an arc did not strike each half cycle, but the voltage did drop in some cases to a value intermediate between that of the arc and the normal cathode drop. The explanation for this behavior is not known. The graphite electrodes for this oscillogram were obtained from 2 different sources which may account for the differences between the individual characteristics; this will be discussed later in this paper. By comparing Figs. 2 and 3, it may be seen that the duration of the glow discharge which precedes the arc is shortened greatly at the higher pressures.

The variation in reignition potential between pure graphite electrodes as the pressure is changed is shown in Fig. 4 for a range of arc currents. It may be noted that, in general, the reignition potential increases as the current in the arc is decreased, and for low currents the reignition potential is nearly proportional to the pressure; but for currents higher than about 13 amp, the curves show a decrease in reignition potential as the pressure is increased. At about 13 amp the reignition potential seems to be independent of pressure for pressures above 10 cm of mercury, maintaining a value of the order of 550 volts. In every case there is a definite reignition potential which is higher than the arc voltage. For comparison purposes the curve marked "spark," computed from Peek's data,[2] gives the initial breakdown voltage for a gap of 1 mm.

Reignition potential for different arc currents, at constant pressure, is shown by Fig. 5. There are 3 definite regions of behavior. The region between 10 and 15 amp is a transition region, the curves all crossing at about 13 amp and reversing their order. All data for the reignition potentials of these electrodes taken at pressures between 2 and 50 cm of mercury give the same value for a current of about 13 amp. The reason for this is not known.

When 2 different materials are used as electrodes

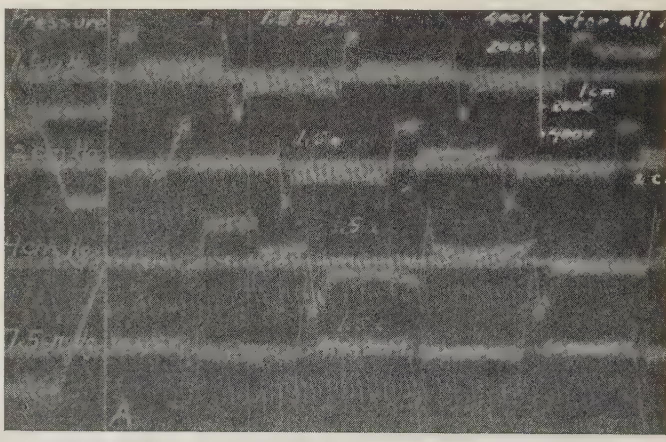


Fig. 2. Oscillogram of arc between pure graphite electrodes

Voltage scale shown in the upper right-hand corner is the same for each pressure; pressures are indicated at the left. The arc starts at "A"

in an alternating current arc, the reignition potential is different in the 2 half cycles and depends on the material of the new cathode for a given current. This is shown in Fig. 6. A curve for 2 pure graphite electrodes is included for comparison. The copper used in these tests was conductor copper; the carbon was the National Carbon Company's projector carbon, made from very pure lamp black having about 0.02 per cent ash. Very small quantities of impuri-

ties such as boron, iron, aluminum, manganese, calcium, and magnesium were present. It may be noted that for the carbon cathode there is for each current a pressure at which the reignition potential is a maximum. When copper is the cathode this effect is not observed.

The results of using carbons that were impregnated with a fair quantity of sodium hydroxide against untreated carbons of the same stock are shown in Fig. 7. The reignition potentials of both the treated and the untreated electrodes were reduced very markedly from the reignition potentials necessary when the untreated electrode was run against copper. In Fig. 7 are shown also the results obtained from using a pure graphite electrode operating against a carbon electrode containing about 35 per cent ash, consisting of 15 per cent of the rare earths, cerium, neodymium, and lanthanum, and 20 per cent calcium fluoride. The curves in Fig. 7 show the remarkable lowering of the reignition potential of the arc because of impurities in one of the electrodes. It is interesting to note that the reignition potential of the pure electrode is affected almost as much as that of the one containing the impurities.

Table I shows that in general the reignition potential is higher for materials of high thermal conductivity, other conditions such as current, pressure, gas, and freedom of impurities, being the same. As the current is increased the decrease in reignition potential is greater for the materials having the lowest thermal conductivity. Preliminary experiments indicate that the reignition potential is a function of the frequency of the arc current, the reignition potential decreasing as the frequency is increased.

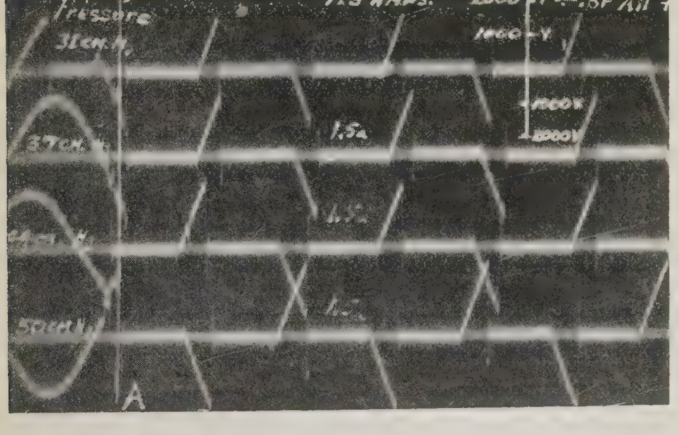


Fig. 3. Oscillogram of arc between pure graphite electrodes

Voltage scale shown in upper right-hand corner is the same for each pressure; pressures are indicated at the left. The arc starts at "A"

Discussion of Results

For the values of pressure, current, and frequency at which this work was done the reignition potential would be approximately the same as the sparking potential if the characteristics of the electrodes did not change during the discharge. This is true because the time required for all the ions and electrons to recombine is extremely short.[3] There may be some slight effect due to an increase in the average temperature of the gas; but large deviations between the reignition potential and the sparking potential must be explained by changes in the properties of the electrodes, and particularly in that electrode which is to become the cathode. Only those changes need be considered that would affect the number of electrons emitted by the cathode or the ease with which they might be emitted by high intensity electric fields. The only factors would seem to be the temperature of *that portion of the electrode which emits electrons* and the presence of electropositive materials having low work functions.

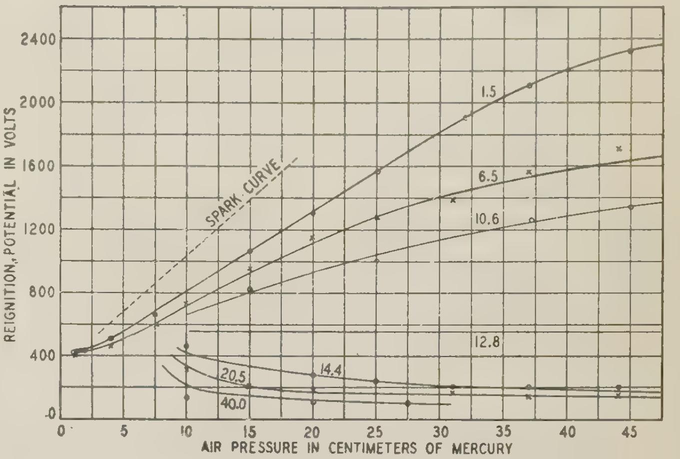


Fig. 4. Arc reignition potentials for pure graphite electrodes

Numerical designations on curves indicate arc currents in amperes

At high temperatures the electric field intensity necessary to produce sufficient electrons to maintain the arc is reduced. If the temperature of the electrode is high enough a sufficient number of electrons may be emitted by thermionic action to reignite the arc with a voltage no higher than that required to maintain it. This latter condition did not obtain in any of the cases cited in this paper, since in all cases a reignition potential was necessary. At the higher pressures and at the higher currents with carbon electrodes, this reignition potential was not high. It is believed that in these cases the carbons were hot enough to emit some thermions though not sufficient in number for the large current density known to exist at the cathode spot, namely, a density of the order of 1,000 amp per square centimeter. When the reignition potential is relatively low, sufficient electrons to maintain the arc probably are produced by a combination of high temperature and high intensity electric field. It is interesting to note that at the low values of current and pressure the reignition potential for carbon is almost as high as for copper. Here the temperature is too low to play any essential part and the restriking of the arc is due to the electric field of high intensity that exists there.

It is well known that field currents due to high intensity electric fields are independent of the temperature of the electrodes until their temperature exceeds about 1,000 deg K.[4] Consequently, it is only at temperatures higher than this that any marked difference between the reignition potential and the sparking potential would be expected. If the temperature is lower than this the difference between the sparking potential and the reignition potential might be due to a greater number of ions and electrons remaining in the space between the electrodes, because of previous arc current, when the arc is restruck. The fact that the reignition potential does not decrease with an increase of the average temperature of the electrode, i. e., it is not noticeably lower after 10 half cycles than after the first half cycle, is in accord with the theory that the field current is independent of temperature provided the temperature is low.

Table I—Effect of Thermal Conductivity of Electrodes on Reignition Potential

Material	Coefficient of Thermal Conductivity	Reignition Potentials (Volts) for Various Arc Currents and Pressures: 1.5 Amp, 25 Cm Hg	1.5 Amp, 50 Cm Hg	8.1 Amp, 25 Cm Hg	8.1 Amp, 50 Cm Hg	12.3 Amp, 25 Cm Hg	12.3 Amp, 50 Cm Hg
Carbon	0.09	1,400	2,330	450	400	200	150
Graphite	0.25	1,575	2,425	1,210	1,550	730	900
Copper	0.80	1,656	2,850	1,400	1,800	1,000	1,600

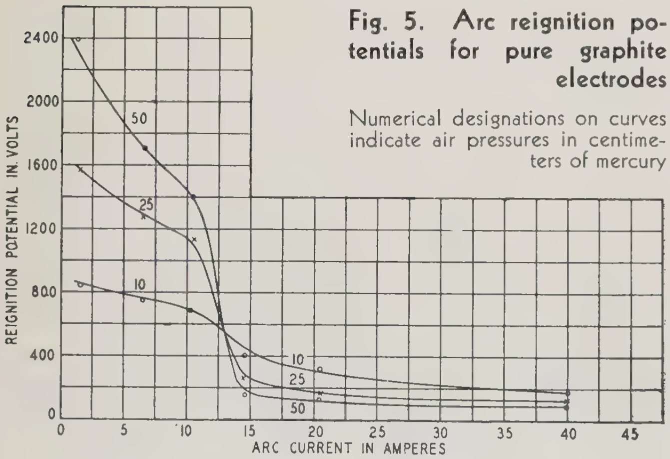


Fig. 5. Arc reignition potentials for pure graphite electrodes

Numerical designations on curves indicate air pressures in centimeters of mercury

On the other hand anything that either increases the temperature of the cathode spot or decreases the cooling while that electrode is anode, is found to decrease the reignition potential. Thus both an increase in current and an increase in pressure cause a greater difference between the reignition potential and the sparking potential because both increase the temperature of the cathode spot. Increases in pressure increase the temperature of the cathode spot because the size of the cathode spot decreases as the pressure increases, and consequently the current density to the cathode spot is increased. Higher frequency has been found to decrease the reignition potential because it allows less time for the cathode spot to cool. In the same way it is found that a higher heat conductivity of the electrode, in general, is accompanied by a higher reignition potential. The reason that the reignition potential for copper is higher than that of graphite and that of carbon is the lowest of the three is believed to be due, at least at the relatively low pressures, to the fact that their heat conductivities are in the same order—copper, graphite, and carbon.

Effect of Impurities

Materials that have a low work function will emit electrons much more readily than those with a high work function. Consequently if there is in the electrodes impurities such as the alkali earths, which have a much lower value of work function than the electrode material itself, their reignition potentials would be expected to be much lower than that of a pure electrode. The experimental results show that this is true. The experiments show that the amount of such impurity need be very small to affect the reignition potential greatly, for if a pure material is used as one electrode, its reignition potential is decreased nearly as much as that of the electrode having the impurity in it. Since material is being vaporized continuously from the surfaces of both electrodes, there can be no accumulation of impurities on the pure electrode. A trace of impurities such as the alkali metals in relatively pure electrodes can account for the random variation of the reignition potential. The reignition potential would be low if a trace of alkali metal happened to be on the surface of the electrode becoming the cathode.

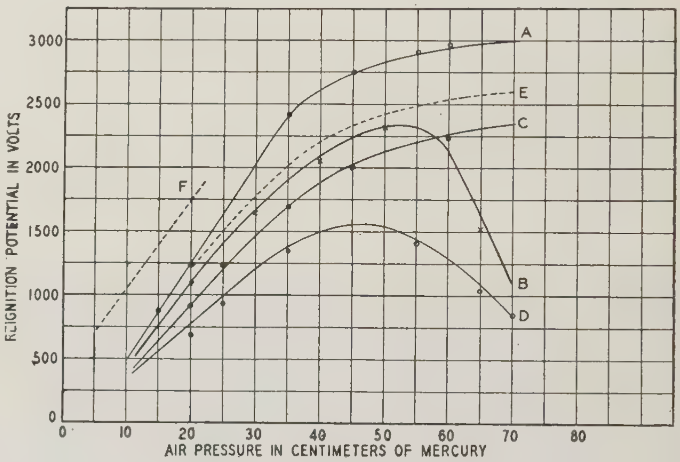


Fig. 6. Reignition potentials of copper-carbon arcs

A—Copper cathode, carbon anode, current 1.5 amp
B—Carbon cathode, copper anode, current 1.5 amp
C—Copper cathode, carbon anode, current 4.8 amp
D—Carbon cathode, copper anode, current 4.8 amp
E—Both electrodes pure graphite, current 1.5 amp
F—Spark curve

All the experimental facts are in accord with the following theory of the transition from the glow discharge to an arc which has been proposed previously by one of the authors:[5] When the current reverses, a glow discharge first is formed with a relatively high

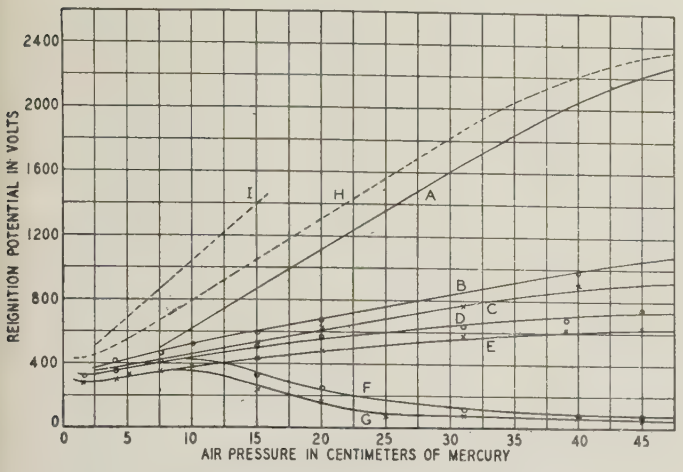


Fig. 7. Effects of impurities on the reignition potentials of carbon arcs

A—Carbon cathode, copper anode, 1.5 amp
B—Carbon cathode, carbon anode with 15% rare earths, 1.5 amp
C—Carbon cathode with 15% rare earths, carbon anode, 1.5 amp
D—Carbon cathode, carbon anode treated with sodium hydroxide, 1.5 amp
E—Carbon cathode treated with sodium hydroxide, carbon anode, 1.5 amp
F—Same as D, but for 6.5 amp
G—Same as E, but for 6.5 amp
H—Both electrodes pure graphite, 1.5 amp
I—Spark curve

cathode drop. As the current density at the cathode increases in the region of the abnormal cathode drop, the magnitude of the cathode drop increases and also this cathode drop occurs in a region closer to the cathode. Both of these effects cause an increase in the intensity of the electric field existing in the cathode drop and consequently increase the energy that the positive ions have when they hit the cathode. As the energy of the positive ions increases, they produce a larger number of electrons from the cathode by bombardment. If now some impurity is assumed on the surface of the cathode or some irregularity that produces a high intensity local electric field, then that portion of the cathode will produce a larger number of electrons than any other portion of the cathode. The electrons freed from the cathode will produce ionization that will be more intense near the active spot on the cathode surface. Due to the high mobility of the electrons compared to the positive ions, the former will disperse into the body of the gas leaving behind the positively charged gas ions. This will increase further the field near the active surface of the cathode with a corresponding increase in the number of electrons emitted from that spot. This process is cumulative and proceeds rapidly until the intensity of the electric field existing at this active spot is high enough to pull large numbers of electrons from the cathode surface. When this occurs an arc exists with its characteristic "hot spot" with a very high current density and with a low cathode drop. A high temperature at the cathode will decrease the magnitude of the electric field necessary to produce these electrons.

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A Survey of Hydroelectric Developments—II

A general outline of the status of modern hydroelectric developments is presented in this report by an A.I.E.E. subcommittee,* continued from the June issue.

IN THE PART of this paper published in the June 1934 issue of Electrical Engineering beginning on p. 988 the present trend in utilization of water power, and the subject of hydroelectric and hydrodynamic research were discussed. Statistics concerning the developed water power of the world are given on this and the following pages.

Water Power as Part of the General Energy Supply

The present civilization depends on constantly increasing amounts of energy that are spent to satisfy the varied requirements of the human race. The principal sources of energy are the carbon deposits contained in the earth's crust (coal, oil, and gas) and water power.

Table I, compiled from World Power Conference data, compares the relative importance of different energy sources of the world on the basis of energy production. While the table is for the year 1927, the present relationship is substantially the same.

Tables II and III show the relative importance of different energy sources, using the installed prime mover capacity as a basis of comparison. These data, applying only to the United States, were supplied by Prof. C. R. Daugherty of the University of Pittsburgh (Pa.). The importance of automobiles is quite evident. Also of considerable interest is the rapid increase in the capacity of steam driven prime movers, internal combustion engines, and water wheels. Although the installed capacity of water wheels is small compared with that of other prime movers, the amount of energy generated per installed horsepower is comparatively large.

Developed Water Power of the World

Recently several different agencies, such as the World Power Conference, the United States Geological Survey, and others, were collecting and publishing data pertaining to the ultimate and developed water power of the world.

The usual difficulties in the collection of data for a world-wide survey are increased by the uncertainty as to the definition of ultimate and developed capacity. Exact statistical data even on the developed water power of the world are not available. All obtainable information is to be considered as approximate because of the uncertainty in the ratings of hydroelectric units and also because of the absence in many countries of reliable information collecting agencies. The published data give aggregate capacities of the different countries. Such data are necessary, but do not give all the information desirable.

In making the present survey a new method was used, which seems to give additional information of considerable importance. This method consists in making a survey of the hydraulic turbines produced in the different countries of the world.

World Production of Hydraulic Turbines

The present status of the turbine art is such that it seems justifiable to classify the different developments as high, medium, and low head developments depending upon the kind of turbines. High head developments would be those using impulse turbines, better known the world over as Pelton turbines; medium head developments, those using Francis turbines; and low head developments, those using any kind of propeller turbines with fixed or adjustable blades, including the well-known Kaplan turbines.

Although such classification may place some of the developments in 2 classes (when 2 different kinds of turbines are used) or show an overlapping of heads, nevertheless it seems better justified than a limiting head arbitrarily chosen. By such classification of the data pertaining to turbines manufactured in different parts of the world, a complete picture can be formed of the developed water power represented by numerous very different developments distributed throughout many countries. Notwithstanding the many countries in which water power developments are located, the number of manufacturers of hydraulic turbines is rather limited.

Tables IV, V, VI, and VII give data on the hydraulic turbine industry in the United States, Canada, Europe, and Japan, during the 5-yr period 1928 to 1932, inclusive. Table VIII gives a world summary for the same period; the data of this table cover well over 90 per cent of the world production of modern water wheels.

In studying these tables, the large aggregate capacity of hydraulic turbines produced in Europe may be noted, also the considerable difference between water power practice in the United States and Canada and that in Europe.

The large proportion of Pelton turbines built in Europe reflects the importance of the high head

Concluding part of a report prepared by the A.I.E.E. subcommittee on hydroelectric survey recommended for publication by the A.I.E.E. committee on power generation, and discussed at the A.I.E.E. summer convention, Hot Springs, Va., June 25–29, 1934. *Not published in pamphlet form.*

*For subcommittee personnel, see Electrical Engineering, June 1934, p. 988.

developments in the Alps and Pyrenees, as well as the use of such European turbines for high head developments in other parts of the world.

So far as low head developments are concerned, it is of interest to note that propeller turbines with fixed or manually operated blades are much more popular than Kaplan turbines (propeller type with automatically adjustable blades) in the United States and Canada, and that there is almost an absence of propeller and Kaplan turbines in Japan. In Europe, 76 per cent of the low head turbines and nearly 13 per cent of all turbines produced are of the Kaplan type. The probability is that the future trend in the United States and Canada will be to increase considerably the percentage of the aggregate horsepower capacity of Kaplan turbines, with a corresponding reduction in the percentage of propeller and Francis turbines.

Developed Water Power in Different Countries

According to the best possible estimates, the developed water power of the world in the year 1933 approaches 60 million shaft horsepower for turbines installed and in actual operation. Table IX shows the distribution of the developed water power among the different countries of the world. From these data it can be seen that at present the water power actually developed is confined mostly to industrialized and highly developed countries. About 24 million horsepower or 40 per cent of the world total is located on the North American continent, about 28 million or 47 per cent in Europe, and about 6 million or 10 per cent in Japan. The appreciable water power possibilities are not utilized at all in the less developed countries, most of which are situated in the mainland of Asia, Africa, and South America.

The present tendency is to concentrate in a single development as large capacities as possible. In

Table I—Millions of Kilowatt Hours Produced in the World During the Year 1927, Assuming All Fuel Is Transformed into Electrical Energy

Source	America	Europe	Asia	Oceania	Africa	World
Coal	558,200	649,100	74,200	17,200	12,100	1,310,800
Oil	222,000	24,800	14,600			261,400
Water Power	42,000	35,000	6,500	900	400	84,800
Totals	822,200	708,900	95,300	18,100	12,500	1,657,000

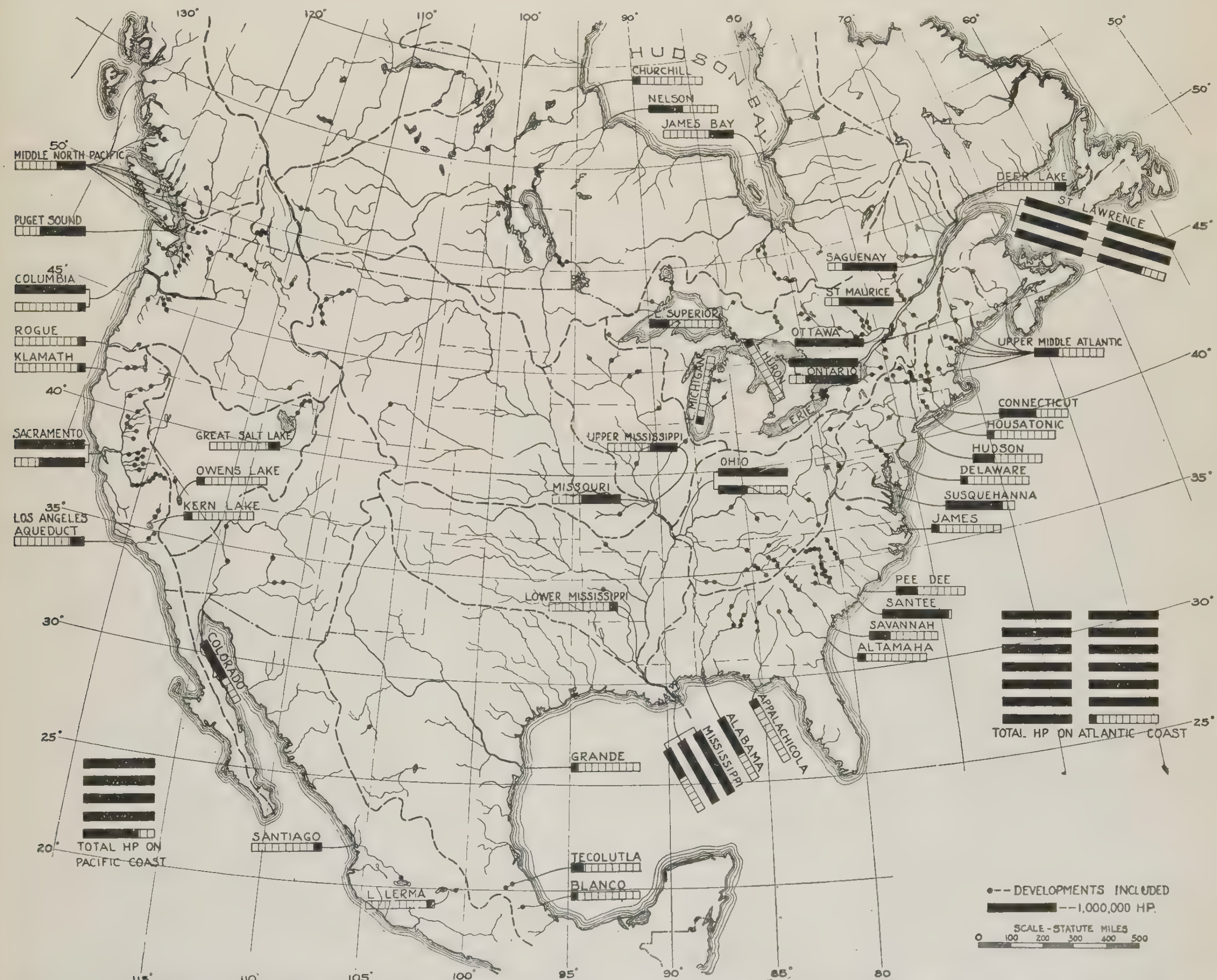


Fig. 2. Aggregate horsepower at turbine shafts installed or being installed (1934) in the different drainage basins in North America, based upon hydroelectric developments exceeding 20,000 hp ultimate capacity

Table X are listed the major developments of the world in operation or under construction, classified according to the proposed ultimate aggregate horsepower capacity at the turbine shafts. A study of this table discloses that a few of the power plants in the United States and Canada after ultimate development will be in the 2,000,000-hp class. Only a few years ago such large plants were considered impractical. The expectations are that the future developments on the Columbia River in the United States and in some parts of Africa and South America will result in power plants of considerably larger capacities.

Major Water Power Developments of the North American Continent

Major developments on the North American continent are shown on Fig. 1, classified according to the drainage areas as established by the United States Geological Survey. Each development shown on the map is listed in Table XI under the corresponding drainage area and number, together with pertinent data. The map and table cover developments the ultimate capacity of which is 20,000 hp or over at the turbine shafts and includes all developments that were in operation or construction in the year 1934. These data probably include more than 75 per cent of the total capacity of the developments of the North American continent.

Table XII gives the aggregate capacity of turbines installed or being installed classified according to the different drainage basins. Tables XIII and XIV give the aggregate capacity of turbines installed or in installation in different drainage areas and in the main drainage basins of the North American continent. These 3 tables are based upon data contained in Table XI.

These tables indicate the large aggregate turbine capacities installed in a few of the drainage basins in the United States and Canada. Table XIII shows also the particular importance of the Great Lakes and St. Lawrence River drainage basin for Canada.

Based on the same data the aggregate horsepower capacity at turbine shafts in the different drainage basins in North America are shown in Fig. 2. The completely blackened rectangles representing each one million horsepower and the partly blackened rectangles a corresponding part of one million horsepower. The large capacities installed on the St.

Table II—Classification and Aggregate Horsepower of Prime Movers Installed in the United States

Year	Steam Engines and Turbines	Internal Combustion Engines (Not in Automobiles)	Wind Power (Sailing Ships and Windmills)	Work Animals	Automobiles: Productive	Automobiles: Pleasure	Total Without Water Wheels	Water Wheels	Totals
	Thousands of Horsepower								
1869	6,215		343	11,275			17,833	1,205	19,038
1889	24,294	9	511	21,311			46,125	1,512	47,637
1909	77,236	5,541	701	25,262	256	7,458	116,454	3,860	120,314
1919	116,348	16,704	665	24,221	10,964	219,468	388,270	7,241	395,611
1929	173,610	31,951	678	19,561	162,483	1,262,497	1,650,780	12,777	1,663,557

Table III—Power Applications in the United States—Aggregate Horsepower Capacity of Prime Movers

Year	Manufacturers, Mines, and Quarries	Agriculture, Irrigation, and Drainage	Electric Central Stations	Steam and Electric Railroads	Ships	Work Animals Not on Farms	Commercial Aircraft	Automobiles: Productive	Automobiles: Pleasure	Totals
	Thousands of Horsepower									
1869	2,696	9,588		4,100	967	1,687				19,038
1889	7,150	19,868	120	16,440	1,384	2,675				47,637
1909	21,206	31,118	5,225	48,491	3,155	3,405		256	7,458	120,314
1919	25,175	39,713	15,250	76,660	6,402	1,979		10,964	219,468	395,611
1929	25,606	44,582	43,000	111,881	9,017	1,400	3,091	162,483	1,262,497	1,663,557

Table IV—Aggregated Horsepower Capacity of Hydraulic Turbines Manufactured in the United States and Canada

Year	Type of Turbines: Pelton	Francis	Propeller	Kaplan	Totals
1928	42,200	1,495,303	84,317	13,631	1,635,451
1929	73,200	1,233,990	128,729	28,590	1,464,579
1930	75,185	1,325,724	347,228	138,125	1,886,262
1931	2,708	603,950	10,700	140,698	758,056
1932		27,960	1,313		29,273
Totals	193,293	4,686,927	572,357	321,044	5,773,621
Per Cent of Total	3.4	81.1	9.9	5.6	100

This table is based upon information supplied by the following manufacturing companies: Allis-Chalmers, Canadian Allis-Chalmers, I. P. Morris, Dominion Engineering Works, Pelton Water Wheel, S. Morgan Smith, S. Morgan Smith-Inglis, and Newport-News Shipbuilding and Dry Dock. It probably covers at least 95 per cent of the total production in the United States and Canada.

Table V—Aggregate Horsepower Capacity of Hydraulic Turbines Manufactured in Northern Europe (England, Norway, Sweden, Finland)

Year	Type of Turbines: Pelton	Francis	Propeller	Kaplan	Totals
1928	157,627	85,144	2,060	32,401	277,232
1929	75,114	324,147	1,360	15,202	415,823
1930	105,332	168,794	2,030	92,661	367,817
1931	29,633	360,874	100	88,487	479,094
1932	13,620	96,331		30,360	140,311
Totals	380,326	1,035,290	5,550	259,111	1,680,277
Per Cent of Total	22.8	61.5	0.3	15.4	100

This table is based upon information supplied by the following manufacturing companies: Boving & Co. Limited, England; A/S Kvaerner Brug, Norway; A/B Karlstads Mekaniska Verkstad, Verkstaden, Kristinehamn, Sweden; and Tammerfors Linne & Jern Manufactur A/B, Finland. It probably covers at least 90 per cent of the total production in northern Europe.

Table VI—Aggregate Horsepower Capacity of Hydraulic Turbines Manufactured in Central and Southern Europe (Switzerland, France, Germany, Italy)

Year	Pelton	Francis	Propeller	Kaplan	Totals
	Type of Turbines				
1928	788,639	1,238,621	255,336	288,863	2,571,459
1929	475,744	1,233,216	50,898	154,180	1,914,038
1930	378,913	834,657	27,823	182,637	1,424,030
1931	210,328	376,946	11,495	188,102	786,871
1932	311,533	80,380	17,395	64,977	474,285
Totals	2,165,157	3,763,820	362,947	878,759	7,170,683
Per Cent of Total	30.2	52.5	5.1	12.2	100

This table is based upon information supplied by the following manufacturing companies: Ateliers des Charmilles, Switzerland; Escher Wyss, Switzerland; Th. Bell, Switzerland; Ateliers Neyret-Beylier & Piccard-Pictet, France; Schneider, Jaquet & Cie, France; Constructions Electriques et Mecaniques ALSTHOM, France; Société Anonyme Tosi-Dujardin, France; J. M. Voith, Germany; Société Franco Tosi & San Giorgio, Italy; S. A. dePretto-Escher Wyss, Italy; and Construzioni Meccaniche Riva, Italy. It probably covers at least 90 per cent of the total production of central and southern Europe.

Table VII—Aggregate Horsepower Capacity of Hydraulic Turbines Manufactured in Japan

Year	Pelton	Francis	Propeller	Kaplan	Totals
	Type of Turbines				
1928	22,736	277,588			300,324
1929	33,923	282,331			316,254
1930	37,813	252,180	1,925	2,000	293,918
1931	73,805	111,951	61		185,817
1932	11,707	87,699	2,513	2	101,921
Total	179,984	1,011,749	4,499	2,002	1,198,234
Per Cent of Total	15.00	84.5	0.4	0.1	100

This table is based upon information supplied by the following manufacturing companies: Dengyosha Prime Mover Works, Ltd.; Hitachi, Ltd.; and Mitsubishi Shipbuilding Works, Ltd. It probably covers at least 95 per cent of the total production in Japan.

Table IX—Developed Water Powers of the World—at the Turbine Shafts

Millions of Horsepower 1933		Millions of Horsepower 1933	
United States	15.8	India	0.7
Canada	7.0	Mexico	0.6
Italy	7.0	Finland	0.5
Japan	5.6	England	0.4
France	4.0	New Zealand	0.3
Germany	3.5	Jugoslavia	0.2
Switzerland	3.5	Czechoslovakia	0.2
Norway	2.5	Chile	0.2
Sweden	2.0	Ireland	0.2
Spain	1.2	New Foundland	0.2
U. S. S. R.	1.0	Chosen	0.1
Austria	1.0	Tasmania	0.1
Brazil	0.8		
		Total	58.6

Lawrence River, as well as the amount of power developed in the Hudson Bay, may be noticed. The Santee River seems to be the most highly developed river in proportion to its length and drainage area.

Table X—Major Developments of the World, in Operation or Under Construction, Classified According to the Ultimate Aggregate Horsepower Capacity at the Turbine Shafts

Development	Country	River	Capacity in Horsepower: Ultimate	Capacity in Horsepower: Installed or in Installation*
Developments of more than 500,000 Horsepower				
Grand Coulee	U. S.	Columbia	2,660,000	*147,000
Beauharnois	Canada	St. Lawrence	2,000,000	266,000
Boulder (Hoover)	U. S.	Colorado	1,835,000	*515,000
Shipshaw (Chute a Caron)	Canada	Saguenay	1,260,000	260,000
Dnieperstroy	U. S. S. R.	Dnieper	810,000	810,000
Serra do Cubato	Brazil	Tieté	750,000	166,000
Bonneville	U. S.	Columbia	688,000	*114,600
Wilson Dam (Muscle Shoals)	U. S.	Tennessee	610,000	260,000
Conowingo	U. S.	Susquehanna	594,000	378,000
Queenston	Canada	Niagara	560,000	560,000
Dura	Norway	Sunndalfjord	550,000	*550,000
Ile Maligne	Canada	Saguenay	540,000	495,000
Fort Peck	U. S.	Missouri	532,000	*
Safe Harbor	U. S.	Susquehanna	510,000	212,500
Developments of from 200,000 to 500,000 Horsepower				
Schoellkopf	U. S.	Niagara	452,500	452,500
Paugan	Canada	Gatineau	476,000	238,000
Galleto	Italy	Nera	400,000	200,000
Wheeler	U. S.	Tennessee	375,000	* 48,000
Saluda	U. S.	Saluda	330,000	220,000
Abitibi Canyon	Canada	Abitibi	330,000	132,000
Diablo	U. S.	Skagit	320,000	*166,000
Gorge	U. S.	Skagit	320,000	78,000
Esla	Spain	Esla	300,000	*225,000
Bridge River	Canada	Bridge	300,000	* 56,000
Carlo Cicogna (Cardano)	Italy	Isacro	285,000	269,000
Chats Falls	Canada	Ottawa	280,000	224,000
Shawinigan	Canada	St. Maurice	278,500	278,500
Brommat	France	Bromme	270,000	270,000
Bagnel (Osage)	U. S.	Osage	268,000	201,000
Rapid Blanc	Canada	St. Maurice	240,000	160,000
Flathead	U. S.	Flathead	234,000	*
Ardnacrusha	Irish Free State	Ardnacrusha	230,000	155,000
Dixence	Switzerland	Dixence	225,000	*225,000
Seven Sisters	Canada	Winnipeg	225,000	112,500
Cedars	Canada	St. Lawrence	220,000	220,000
Kembs	France	Rhine	220,000	*183,000
Timpa Grande	Italy	Arvo	220,000	107,000
Sarrans	France	Truyere	200,000	156,000
Jordan	U. S.	Coosa	216,000	144,000
Imatra	Finland	Vuoksen	216,000	108,000
Comerford (15 Mile Falls)	U. S.	Connecticut	215,000	215,000
Mareges	France	Dordogne	210,000	*210,000
Rock Island	U. S.	Columbia	210,000	84,000
Ilha dos Pambos	Brazil	Parahyba	204,000	116,000
Trollhattan	Sweden	Gotaelf	200,000	164,000
Arapuni	New Zealand	Waikato	200,000	100,000

* Asterisk indicates plants under construction.

Table VIII—World Production of Hydraulic Turbines During the 5-Year Period 1928 to 1932, Inclusive

	Type of Turbines: Pelton		Francis		Propeller		Kaplan		Totals	
	Aggregate Horsepower	Per Cent	Aggregate Horsepower	Per Cent	Aggregate Horsepower	Per Cent	Aggregate Horsepower	Per Cent	Aggregate Horsepower	Per Cent
United States and Canada	193,293	3.4	4,686,927	81.1	572,357	9.9	321,044	5.6	5,773,621	100
Europe	2,545,483	28.8	4,799,110	54.1	368,497	4.2	1,137,870	12.9	8,850,960	100
Japan	179,984	15.0	1,011,749	84.5	4,499	0.4	2,002	0.1	1,198,234	100
Totals	2,918,760	18.4	10,497,786	66.3	945,353	6.1	1,460,916	9.2	15,822,815	100

This table probably covers at least 90 per cent of the World production.

Table XI—Major North American Hydroelectric Power Developments* in Operation or Under Construction (1934) the Ultimate Capacity of Which Is More Than 20,000 Hp on the Turbine Shafts

Development	River	Drainage Basin	State or Province	Operating Company	Ultimate Horsepower	Installed or in Actual Installation: Hp	Year of Initial Operation	Year of Completion
I—North and Middle Atlantic Drainage Area								
Deer Lake	Humber	Deer Lake	Newfoundland	International Power & Paper Co. of Newfoundland Ltd.	156,000	156,000	1925	1930
Grand Falls	St. John	St. John	New Brunswick	Gatineau Pwr. Co.	80,000	80,000	1928	1931
Millinocket	Penobscot	Penobscot	Maine	Great Northern Paper Co.	42,500	42,500	1900	1922
Wyman	Kennebec	Kennebec	Maine	Cen. Maine Pwr. Co.	102,000	68,000	1931	1931
Rumford Falls	Androscoggin	Androscoggin	Maine	Rumford Falls Pwr. Co.	42,000	36,000	1903	1926
Gulf Island	Androscoggin	Androscoggin	Maine	Cen. Maine Pwr. Co.	27,000	27,000		1925
Lewiston	Androscoggin	Androscoggin	Maine	Union Water Pwr. Co.	25,000	23,666	1856	1921
Bonny Eagle & West Buxton	Saco	Saco	Maine	Cumberland County Pwr. & Lt. Co.	23,000	23,000		1927
Amoskeag	Merrimac	Merrimac	New Hampshire	Amoskeag Mfg. Co.	...	33,910		...
Comerford (15 Mile Falls)	Connecticut	Connecticut	New Hampshire & Vermont	Connecticut River Power Co.	215,000	215,000	1930	1930
Bellows Falls	Connecticut	Connecticut	New Hampshire	Bellows Falls Hydro Elec. Corp.	66,000	66,000	1928	1928
Vernon	Connecticut	Connecticut	New Hampshire & Vermont	Connecticut River Power Co.	41;700	41,700	1909	1921
Turners Falls (Cabot)	Connecticut	Connecticut	Massachusetts	Turners Falls Pwr. & Elec. Co.	77,000	66,000	1916	1916
Harriman	Deerfield	Connecticut	Vermont	New England Pwr. Co.	60,000	60,000	1924	1925
Deerfield No. 5	Deerfield	Connecticut	Massachusetts	New England Pwr. Co.	20,400	20,400	1915	1915
Cobble Mt.	Westfield Little	Connecticut	Massachusetts	Turners Falls Pwr. & Elec. Co.	46,950	46,950	1932	1932
Rocky River	Housatonic	Housatonic	Connecticut	Connecticut Lt. & Pwr. Co.	66,000	33,000	1929	1929
Stevenson	Housatonic	Housatonic	Connecticut	Connecticut Lt. & Pwr. Co.	38,000	25,000	1919	1919
E. J. West	Sacandaga	Hudson	New York	New York Pwr. & Lt. Corp.	51,500	34,300	1930	1930
Spier Falls	Hudson	Hudson	New York	New York Pwr. & Lt. Corp.	154,000	92,200	1904	1930
Sherman Island	Hudson	Hudson	New York	Inter. Hydro. Elec. Corp.	60,000	40,000	1923	1923
School Street	Mohawk	Hudson	New York	New York Pwr. & Lt. Corp.	54,000	54,000	1915	1924
Schaghticoke	Hoosic	Hudson	New York	New York Pwr. & Lt. Corp.	20,000	20,000	1908	1908
Beardslee Falls	E. Canada Cr.	Hudson	New York	New York Pwr. & Lt. Corp.	30,000	21,200	1924	1924
Trenton Falls	W. Canada Cr.	Hudson	New York	Utica Gas & Elec. Co.	36,800	36,800	1901	1922
Wallenpaupack	Wallenpaupack	Delaware	Pennsylvania	Penna. Pwr. & Lt. Co.	57,000	57,000	1926	1926
York Haven	Susquehanna	Susquehanna	Pennsylvania	Metropolitan Edison Co.	29,213	29,213	1904	1914
Safe Harbor	Susquehanna	Susquehanna	Pennsylvania	Safe Harbor Water Pwr. Corp.	510,000	255,000	1931	1934
Holtwood	Susquehanna	Susquehanna	Pennsylvania	Penna. Water & Pwr. Co.	158,000	158,000	1910	1924
Conowingo	Susquehanna	Susquehanna	Maryland	Susquehanna Elec. Co.	594,000	378,000	1928	1928
II—South Atlantic and East Gulf of Mexico Drainage Area								
Reusens	James	James	Virginia	Appalachian Electric Pwr. Co.	20,200	20,200	1904	1931
High Rock	Yadkin	Pee Dee	North Carolina	Carolina Alum. Co.	44,100	44,100	1928	1928
Badin Narrows	Yadkin	Pee Dee	North Carolina	Carolina Alum. Co.	108,000	108,000	1917	1924
Yadkin Falls	Yadkin	Pee Dee	North Carolina	Carolina Alum. Co.	28,980	28,980	1919	1919
Norwood	Yadkin	Pee Dee	North Carolina	Carolina Pwr. & Lt. Co.	118,900	87,800	1928	1928
Blewett	Pee Dee	Pee Dee	North Carolina	Carolina Pwr. & Lt. Co.	34,000	34,000	1912	1912
Bridgewater	Catawba	Santee	North Carolina	Duke Pwr. Co.	35,600	35,600	1919	1919
Rhodhiss	Catawba	Santee	North Carolina	Duke Pwr. Co.	42,000	42,000	1925	1925
Oxford	Catawba	Santee	North Carolina	Duke Pwr. Co.	56,000	56,000	1928	1928
Lookout Shoals	Catawba	Santee	North Carolina	Duke Pwr. Co.	33,840	33,840	1915	1915
Mountain Island	Catawba	Santee	North Carolina	Duke Pwr. Co.	82,400	82,400	1923	1923
Catawba	Catawba	Santee	South Carolina	Duke Pwr. Co.	86,000	86,000	1925	1925
Fishing Creek	Catawba	Santee	South Carolina	Duke Pwr. Co.	64,125	64,125	1916	1916
Great Falls	Catawba	Santee	South Carolina	Duke Pwr. Co.	41,600	41,600	1907	1907
Dearborn	Catawba	Santee	South Carolina	Duke Pwr. Co.	52,500	52,500	1923	1923
Cedar Creek	Catawba	Santee	South Carolina	Duke Pwr. Co.	51,300	51,300	1926	1926
Rocky Creek	Wateree	Santee	South Carolina	Duke Pwr. Co.	41,600	41,600	1909	1909
Wateree	Wateree	Santee	South Carolina	Duke Pwr. Co.	105,500	105,500	1919	1919
99 Islands	Broad	Santee	South Carolina	Duke Pwr. Co.	31,200	31,200	1910	1910
Parr Shoals	Broad	Santee	South Carolina	Broad River Pwr. Co.	21,600	21,600	1914	1921
Saluda	Saluda	Santee	South Carolina	Lexington Water Pwr. Co.	330,000	220,000	1930	1930
Terrora	Tallulah	Savannah	Georgia	Georgia Pwr. Co.	30,400	30,400	1925	1925
Tallulah Falls	Tallulah	Savannah	Georgia	Georgia Pwr. Co.	108,000	108,000	1913	1913
Tugalo	Tugalo	Savannah	Georgia	Georgia Pwr. Co.	88,000	88,000	1924	1924
Yonah	Tugalo	Savannah	Georgia	Georgia Pwr. Co.	42,600	42,600	1925	1925
Stevens Creek	Savannah	Savannah	Georgia	So. Carolina Pwr. Co.	31,250	25,000	1914	1914
Furman Shoals	Oconee	Altamaha	Georgia	Georiga Pwr. Co.	60,000	60,000	Postponed	
Lloyd Shoals	Ocmulgee	Altamaha	Georgia	Georgia Pwr. Co.	33,000	33,000	1911	1911
Morgan Falls	Chattahoochee	Appalachicola	Georiga	Georgia Pwr. Co.	23,100	23,100	1904	1904
Bartletts Ferry	Chattahoochee	Appalachicola	Georgia	Georgia Pwr. Co.	88,000	66,000	1926	1926
Goat Rock	Chattahoochee	Appalachicola	Georgia	Georgia Pwr. Co.	65,000	25,600	1912	1912
Martin Dam (Cherokee Bluffs)	Tallapoosa	Alabama	Alabama	Alabama Pwr. Co.	180,000	135,000	1927	1927
Upper Tallassee	Tallapoosa	Alabama	Alabama	Alabama Pwr. Co.	75,000	50,000	1928	1928
Thurlow (Lower Tallassee)	Tallapoosa	Alabama	Alabama	Alabama Pwr. Co.	72,000	72,000	1931	1931
Lay Dam (Lock No. 12)	Coosa	Alabama	Alabama	Alabama Pwr. Co.	110,000	110,000	1914	1914
Mitchell	Coosa	Alabama	Alabama	Alabama Pwr. Co.	120,000	72,000	1923	1923
Jordan (Lock No. 18)	Coosa	Alabama	Alabama	Alabama Pwr. Co.	216,000	144,000	1929	1929

* The developments are classified in accordance with the following drainage areas, which may be identified on the accompanying map of the United States:

I	North and Middle Atlantic	V	Missouri River	IX	Gulf of California and Lower South Pacific	XIII	Middle North Pacific
II	South Atlantic and East Gulf of Mexico	VI	Ohio River	X	Great Basin	XIV	Hudson Bay
III	Great Lakes and St. Lawrence River	VII	Lower Mississippi River	XI	Upper South Pacific		
IV	Upper Mississippi River	VIII	Western Gulf of Mexico	XII	Lower North Pacific		

Table XI—(Continued)—Major North American Hydroelectric Power Developments* in Operation or Under Construction (1934) the Ultimate Capacity of Which Is More Than 20,000 Hp on the Turbine Shafts

Development	River	Drainage Basin	State or Province	Operating Company	Ultimate Horsepower	Installed or in Actual Installation: Hp	Year of Initial Operation	Year of Completion
III(A)—Great Lakes Drainage Area								
Thompson	St. Louis	Lake Superior	Minnesota	Minn. Pwr. & Lt. Co.	69,700	69,700	1909	1912
Kakabeka	Kaministiquia	Lake Superior	Ontario	Kaministiquia Pwr. Co.	35,000	35,000	1914	1914
Cameron Falls (Nipigon)	Nipigon	Lake Superior	Ontario	Hydro-Elec. Pwr. Comm.	75,000	75,000	1920	1926
Alexander	Nipigon	Lake Superior	Ontario	Hydro-Elec. Pwr. Comm.	72,000	54,000	1931	1931
High Falls	Michipicoten	Lake Superior	Ontario	Great Lakes Pwr. Co.	35,000	22,000	1929	1931
Sault Ste. Marie	St. Mary	Lake Huron	Ontario	Great Lakes Pwr. Co.	...	41,600	1900	1931
Sault Ste. Marie	St. Mary	Lake Huron	Michigan	Mich. Northern Pwr. Co.	...	40,000	...	...
High Falls	Spanish	Lake Huron	Ontario	Huronian Co.	20,500	20,500	1906	1916
Big Eddy	Spanish	Lake Huron	Ontario	Huronian Co.	28,200	28,200	1929	1929
Espanola	Spanish	Lake Huron	Ontario	Abitibi Pwr. & Paper Co.	20,800	20,800	1911	1911
Hardy	Muskegon	Lake Michigan	Michigan	Consumers Pwr. Co.	40,000	40,000	1931	1931
Junction	Manistee	Lake Michigan	Michigan	Consumers Pwr. Co.	26,675	26,675	1918	1918
Hodenpyl	Manistee	Lake Michigan	Michigan	Consumers Pwr. Co.	24,000	24,000	1925	1925
De Cew Falls	Welland Canal	Lake Ontario	Ontario	Hydro-Elec. Pwr. Comm.	51,500	51,500	1898	1912
Queenston	Niagara	Lake Ontario	Ontario	Hydro-Elec. Pwr. Comm.	560,000	560,000	1921	1930
Ontario Power	Niagara	Lake Ontario	Ontario	Hydro-Elec. Pwr. Comm.	195,700	195,700	1905	1920
Canadian Niagara (Wm. B. Rankin)	Niagara	Lake Ontario	Ontario	Canadian Niagara Pwr. Co.	120,500	120,500	1905	1924
Toronto Power	Niagara	Lake Ontario	Ontario	Hydro-Elec. Pwr. Comm.	160,500	160,500	1906	1914
Schoellkopf	Niagara	Lake Ontario	New York	Niagara Falls Pwr. Co.	452,500	452,500	1907	1924
Adams (American Niagara)	Niagara	Lake Ontario	New York	Niagara Falls Pwr. Co.	105,000	105,000	1895	1904
Rochester No. 5	Genesee	Lake Ontario	New York	Rochester Gas & Elec. Corp.	54,000	54,000	1917	1928
Bennetts Bridge	Salmon	Lake Ontario	New York	Niag. Lockport & Ont. Pwr. Co.	40,000	40,000	1914	1914
Soft Maple	Beaver	Lake Ontario	New York	Northern N. Y. Utilities Inc.	31,500	21,000	1925	1925
III(B)—St. Lawrence River Drainage Area								
Browns Falls	E. Branch Oswegatchie	Oswegatchie	New York	Northern N. Y. Utilities Inc.	23,000	23,000	1923	1923
Colton (Browns Bridge)	Raquette	Raquette	New York	St. Lawrence Valley Pwr. Corp.	37,700	37,700	1919	1928
Massena	St. Lawrence	St. Lawrence	New York	Alum. Co. of America	71,375	71,375	1903	1914
St. Timothee	St. Lawrence	St. Lawrence	Quebec	Canadian Lt. & Pwr. Co.	28,800	28,800	1911	1914
Beauharnois	St. Lawrence	St. Lawrence	Quebec	Beauharnois Lt. Heat & Pwr. Co.	2,000,000	266,000	1932	1934
Quinze (Ka-Ka-Ke Falls)	Quinze	Ottawa	Quebec	Can. Northern Pwr. Corp.	60,000	40,000	1925	1928
Kipawa	Gordon Creek	Ottawa	Quebec	Gatineau Pwr. Co.	24,000	24,000	1920	1926
Bryson	Ottawa	Ottawa	Quebec	Gatineau Pwr. Co.	77,100	51,400	1925	1929
Chats Falls	Ottawa	Ottawa	Quebec & Ontario	Hydro-Elec. Pwr. Comm. Ottawa Valley Pwr. Corp.	280,000	224,000	1931	1932
Chaudiere	Ottawa	Ottawa	Quebec	Gatineau Pwr. Co.	44,100	36,600	1902	1923
Paugan	Gatineau	Ottawa	Quebec	Gatineau Pwr. Co.	476,000	238,000	1928	1931
Chelsea	Gatineau	Ottawa	Quebec	Gatineau Pwr. Co.	170,000	136,000	1927	1929
Farmers	Gatineau	Ottawa	Quebec	Gatineau Pwr. Co.	120,000	96,000	1927	1929
High Falls	Liévre	Ottawa	Quebec	Maclaren-Quebec Pwr. Co.	120,000	90,000	1930	1930
Masson	Liévre	Ottawa	Quebec	Maclaren-Quebec Pwr. Co.		136,000	1933	1933
Cedars	St. Lawrence	St. Lawrence	Quebec	Cedars Rapids Mfg. & Pwr. Co.	220,000	220,000	1914	1924
Montreal Island (Back River)	des Prairies	St. Lawrence	Quebec	Montreal Island Pwr. Co.	75,000	45,000	1929	1929
Chambly	Richelieu	Richelieu	Quebec	Montreal Lt. Heat & Pwr. Co.	21,600	21,600	1899	1899
Hemming Falls	St. Francis	St. Francis	Quebec	Southern Canada Pwr. Corp.	33,600	33,600	1925	1925
Rapide Blanc	St. Maurice	St. Maurice	Quebec	Shawinigan Water & Pwr. Co.	240,000	160,000	1934	1934
Laurentide (Grand Mere)	St. Maurice	St. Maurice	Quebec	Shawinigan Water & Pwr. Co.	189,000	189,000	1915	1930
Shawinigan	St. Maurice	St. Maurice	Quebec	Shawinigan Water & Pwr. Co.	278,500	278,500	1903	1929
LaGabelle	St. Maurice	St. Maurice	Quebec	Shawinigan Water & Pwr. Co.	152,000	152,000	1924	1930
St. Narcisse	St. Lawrence	St. Lawrence	Quebec	North Shore Pwr. Co.	44,400	22,200	1926	1926
St. Fereol	St. Anne de Beaupré	St. Lawrence	Quebec	Quebec Pwr. Co. Ltd.	24,000	24,000	1916	1926
Ile Maligne	Saguenay	Saguenay	Quebec	Duke Price Pwr. Co. Ltd.	540,000	495,000	1925	1925
Shipshaw (Chute à Caron)	Saguenay	Saguenay	Quebec	Alcoa Pwr. Co. Ltd.	1,260,000	260,000	1931	1931
IV—Upper Mississippi River Drainage Area								
Blanchard	Mississippi	Mississippi	Minnesota	Minnesota Pwr. & Lt. Co.	27,000	18,000	1924	1924
St. Croix Falls	St. Croix	St. Croix	Wisconsin	Northern States Pwr. Co.	35,400	35,400	1905	1905
Wissota	Chippewa	Chippewa	Wisconsin	Northern States Pwr. Co.	45,000	45,000	1916	1916
Chippewa Falls	Chippewa	Chippewa	Wisconsin	Northern States Pwr. Co.	30,000	30,000	1928	1928
Prairie Du Sac	Wisconsin	Wisconsin	Wisconsin	Wisconsin Pwr. & Lt. Co.	41,150	41,150	1909	1926
Keokuk	Mississippi	Mississippi	Iowa	Mississippi River Pwr. Co.	184,420	154,420	1913	1913
Lockport	Illinois	Illinois	Illinois	Sanitary District of Chicago	46,000	42,000	1907	1911
V—Missouri River Drainage Area								
Hauser Lake	Missouri	Missouri	Montana	Montana Pwr. Co.	25,000	25,000	1911	1914
Holter	Missouri	Missouri	Montana	Montana Pwr. Co.	70,000	70,000	1918	1918
Black Eagle	Missouri	Missouri	Montana	Montana Pwr. Co.	25,000	25,000	1913	1927
Volta	Missouri	Missouri	Montana	Montana Pwr. Co.	84,000	84,000	1916	1916
Rainbow	Missouri	Missouri	Montana	Montana Pwr. Co.	49,000	49,000	1910	1917
Morony	Missouri	Missouri	Montana	Montana Pwr. Co.	62,000	62,000	1930	1930
Fort Peck	Missouri	Missouri	Montana	U. S. Govt.	532,000	...	1939	...
Casper Alcova	North Platte	North Platte	Wyoming	U. S. Govt.	42,000	42,000	1936	1940
Osage (Bagnell)	Osage	Osage	Missouri	Union Elec. Lt. & Pwr. Co.	268,000	201,000	1931	1931

* The developments are classified in accordance with the following drainage areas, which may be identified on the accompanying map of the United States:

I North and Middle Atlantic
II South Atlantic and East Gulf of Mexico
III Great Lakes and St. Lawrence River
IV Upper Mississippi River
V Missouri River
VI Ohio River
VII Lower Mississippi River
VIII Western Gulf of Mexico
IX Gulf of California and Lower South Pacific
X Great Basin
XI Upper South Pacific
XII Lower North Pacific
XIII Middle North Pacific
XIV Hudson Bay

Table XI—(Continued)—Major North American Hydroelectric Power Developments* in Operation or Under Construction (1934) the Ultimate Capacity of Which Is More Than 20,000 Hp on the Turbine Shafts

Development	River	Drainage Basin	State or Province	Operating Company	Ultimate Horsepower	Installed or in Actual Installation: Hp	Year of Initial Operation	Year of Completion
VI—Ohio River Drainage Area								
Piney	Clarion	Allegheny	Pennsylvania	Clarion River Pwr. Co.	34,000	34,000	1924	1928
Deep Creek	Deep Creek	Monongahela	Maryland	Youghlogheny Hydro Elec. Corp.	24,000	24,000	1925	1925
Lake Lynn (Cheat Haven)	Cheat	Monongahela	W. Virginia	West Penn Pwr. Co.	72,000	72,000	1926	1927
Byllesby	New	New	Virginia	Appalachian Elec. Pwr. Co.	32,000	32,000	1912	1912
Hawks Nest	New	New	W. Virginia	New Kanawha Pwr. Co.	175,000	140,000	1935	1936
Dix Dam	Dix	Dix	Kentucky	Kentucky Utilities Co.	32,724	32,724	1925	1925
Ohio Falls	Ohio	Ohio	Kentucky	Louisville Gas & Elec. Co.	135,000	108,000	1928	1928
Great Falls	Caney Fork	Cumberland	Tennessee	Tenn. Elec. Pwr. Co.	35,510	35,510	1916	1916
Waterville	Pigeon	Tennessee	No. Carolina	Carolina Pwr. & Lt. Co.	147,000	147,000	1930	1930
Norris Dam (Cove Creek)	Clinch	Tennessee	Tennessee	Tenn. Valley Auth.	120,000	120,000	1936	1936
Santeetlah	Cheoah	Tennessee	No. Carolina	Carolina Alum. Co.	66,000	66,000	1927	1927
Cheoah	Little Tenn.	Tennessee	No. Carolina	Carolina Alum. Co.	96,000	96,000	1918	1925
Calderwood	Little Tenn.	Tennessee	Tennessee	Aluminum Co. of America	168,000	112,000	1930	1930
Blue Ridge	Toccoa	Tennessee	Georgia	Tenn. Elec. Pwr. Co.	26,700	26,700	1931	1931
Ocoee No. 1	Ocoee	Tennessee	Tennessee	Tenn. Elec. Pwr. Co.	30,150	30,150	1912	1912
Ocoee No. 2	Ocoee	Tennessee	Tennessee	Tenn. Elec. Pwr. Co.	24,120	24,120	1913	1913
Hales Bar	Tennessee	Tennessee	Tennessee	Tenn. Elec. Pwr. Co.	56,720	56,720	1913	1913
Wheeler (Dam No. 3)	Tennessee	Tennessee	Alabama	Tenn. Valley Auth.	375,000	48,000	1936	...
Wilson Dam (Muscle Shoals)	Tennessee	Tennessee	Alabama	Tenn. Valley Auth.	610,000	260,000	1925	1926
VII—Lower Mississippi River Drainage Area								
Ozark Beach	White	Arkansas	Missouri	Empire Dist. Elec. Co.	48,000	24,000	1913	1931
Carpenter	Ouachita	Red	Arkansas	Arkansas Pwr. & Lt. Co.	118,500	79,000	1931	1932
VIII—Western Gulf of Mexico Drainage Area								
Boquilla	Conchos	Grande	Chihuahua	Cia Agricola y de Fuerza Elec. del Rio Conchos	26,000	26,000	1910	1915
Necaxa	Necaxa	Tecolutla	Puebla	Cia Mex. Luz y Fuerza Motriz, S. A.	108,000	108,000	1912	1923
Tepexic	Necaxa	Tecolutla	Puebla	Cia Mex. Luz y Fuerza Motriz, S. A.	60,000	60,000	...	...
Tuxpango	Blanco	Blanco	Vera Cruz	Puebla Tramway Lt. & Pwr. Co.	50,000	50,000	1911	1931
IX—Gulf of California and Lower South Pacific Drainage Areas								
Boulder (Hoover)	Colorado	Colorado	Ariz. & Nev.	U. S. Govt.	1,835,000	515,000	1935	1941
Parker	Colorado	Colorado	Arizona	U. S. Govt.	160,000		...	...
Verde	Verde	Colorado	Arizona	U. S. Govt.	21,000		...	...
Roosevelt	Salt	Colorado	Arizona	Salt River Valley Water Users Assoc.	26,240	26,240	1907	1924
Horse Mesa	Salt	Colorado	Arizona	Salt River Valley Water Users Assoc.	47,180	47,180	1927	1927
Puente Grande	Santiago	Santiago	Jalisco	Cia Elec. Chapala	22,700	22,700	1912	1912
Tepuxtepec	Lerma	Lerma	Michoacan	Cia Luz y Fuerza del Suroeste de Mexico	130,000	65,000	1930	1930
X—Great Basin Drainage Area								
Soda	Bear	Grt. Salt L.	Idaho	Utah Pwr. & Lt. Co.	20,000	20,000	1924	1924
New Grace	Bear	Grt. Salt L.	Idaho	Utah Pwr. & Lt. Co.	46,000	46,000	1914	1923
Oneida	Bear	Grt. Salt L.	Idaho	Utah Pwr. & Lt. Co.	42,000	42,000	1915	1920
Cutler	Bear	Grt. Salt L.	Utah	Utah Pwr. & Lt. Co.	43,000	43,000	1927	1927
Bishop (11 plants)	Owens	Owens Lake	California	So. Sierras Pwr. Co.	109,420	93,420	1905	1924
XI—Upper South Pacific Drainage Area								
Copco No. 1	Klamath	Klamath	California	Calif.-Oregon Pwr. Co.	37,200	37,200	1925	1925
Copco No. 2	Klamath	Klamath	California	Calif.-Oregon Pwr. Co.	40,000	40,000	1918	1918
Pit No. 1	Pit	Sacramento	California	Pac. Gas & Elec. Co.	93,834	93,834	1922	1922
Pit No. 3	Pit	Sacramento	California	Pac. Gas & Elec. Co.	108,580	108,580	1925	1925
Coleman	Battle Creek	Sacramento	California	Pac. Gas & Elec. Co.	22,118	22,118	1911	1911
Caribou	Feather	Sacramento	California	Grt. West. Pwr. Co. of Calif.	179,738	89,369	1921	1921
Bucks Creek	Bucks Creek	Sacramento	California	Grt. West. Pwr. Co. of Calif.	67,024	67,024	1928	1928
Big Bend (Las Plumas)	Feather	Sacramento	California	Grt. West. Pwr. Co. of Calif.	134,000	87,131	1916	1916
Colgate	Yuba-Mid. Fk.	Sacramento	California	Pac. Gas & Elec. Co.	20,878	20,878	1899	1906
Drum	Bear	Sacramento	California	Pac. Gas & Elec. Co.	73,726	73,726	1913	1928
Eldorado	American-S. Fk.	Sacramento	California	Pac. Gas & Elec. Co.	33,512	33,512	1924	1924
Kern R. No. 3	Kern	Kern Lake	California	So. Calif. Edison Co. Ltd.	46,245	46,245	1921	1921
Kern R. No. 1	Kern	Kern Lake	California	So. Calif. Edison Co. Ltd.	29,490	29,490	1907	1907
Big Creek No. 1	Big Creek	San Joaquin	California	So. Calif. Edison Co. Ltd.	109,920	109,920	1913	1925
Big Creek No. 2	Big Creek	San Joaquin	California	So. Calif. Edison Co. Ltd.	88,470	88,470	1913	1925
Big Creek No. 2a	Big Creek	San Joaquin	California	So. Calif. Edison Co. Ltd.	124,665	124,665	1928	1928
Big Creek No. 3	Big Creek	San Joaquin	California	So. Calif. Edison Co. Ltd.	175,000	131,367	1923	1923

* The developments are classified in accordance with the following drainage areas, which may be identified on the accompanying map of the United States:

I North and Middle Atlantic
II South Atlantic and East Gulf of Mexico
III Great Lakes and St. Lawrence River
IV Upper Mississippi River
V Missouri River
VI Ohio River
VII Lower Mississippi River
VIII Western Gulf of Mexico
IX Gulf of California and Lower South Pacific
X Great Basin
XI Upper South Pacific
XII Lower North Pacific
XIII Middle North Pacific
XIV Hudson Bay

Table XI—(Continued)—Major North American Hydroelectric Power Developments* in Operation or Under Construction (1934) the Ultimate Capacity of Which Is More Than 20,000 Hp on the Turbine Shafts

Development	River	Drainage Basin	State or Province	Operating Company	Ultimate Horsepower	Installed or in Actual Installation: Hp	Year of Initial Operation	Year of Completion
Big Creek No. 8	Big Creek	San Joaquin	California	So. Calif. Edison Co. Ltd	77,750	77,750	1921	1929
Kerchoff	San Joaquin	San Joaquin	California	San Joaquin Lt. & Pwr. Corp	57,105	57,105	1920	1920
San Joaquin No. 1	San Joaquin	San Joaquin	California	San Joaquin Lt. & Pwr. Corp	21,448	21,448	1910	1911
Balch	San Joaquin	San Joaquin	California	San Joaquin Lt. & Pwr. Corp	176,944	44,236	1927	1927
Exchequer	Merced	San Joaquin	California	Merced Irrig. Dist	54,000	42,000	1926	1926
Mocassin	Toulumne	San Joaquin	California	Hetch Hetchy Water Supply	120,000	100,000	1925	1925
Don Pedro	Toulumne	San Joaquin	California	Turlock & Modesto Irrig. Dist	70,000	41,100	1923	1928
Stanislaus	Stanislaus	San Joaquin	California	Pac. Gas & Elec. Co	45,576	45,576	1908	1908
Melones	Stanislaus	San Joaquin	California	Pac. Gas. & Elec. Co	36,193	36,193	1927	1927
Tiger Creek	Mokelumne	San Joaquin	California	Pac. Gas & Elec. Co	80,430	80,430	1931	1931
Electra	Mokelumne	San Joaquin	California	Pac. Gas & Elec. Co	75,000	26,810	1902	...
Pardee	Mokelumne	San Joaquin	California	East Bay Municipal Utility Dist (Oakland)	20,000	20,000	1930	1930
San Francisquito No. 1	Los Angeles Aqueduct	Los Angeles Aqueduct	California	City of Los Angeles	96,200	96,200	1917	1928
San Francisquito No. 2	Los Angeles Aqueduct	Los Angeles Aqueduct	California	City of Los Angeles	62,000	62,000	1920	1932

XII—Lower North Pacific Drainage Area

Development	River	Drainage Basin	State or Province	Operating Company	Ultimate Horsepower	Hp	Year of Initial Operation	Year of Completion
Diablo	Skagit	Puget Sound	Washington	City of Seattle	320,000	166,000	1936	1936
Gorge	Skagit	Puget Sound	Washington	City of Seattle	320,000	78,000	1924	1928
Baker River	Baker	Puget Sound	Washington	Puget Sound Pwr. & Lt. Co	80,429	53,619	1925	...
Snoqualmie	Snoqualmie	Puget Sound	Washington	Puget Sound Pwr. & Lt. Co	26,810	26,810	1899	1911
Cedar Falls	Cedar	Puget Sound	Washington	City of Seattle	56,800	56,800	1904	1929
Electron	Pyallup	Puget Sound	Washington	Puget Sound Pwr. & Lt. Co	30,161	30,161	1904	1929
White River	White	Puget Sound	Washington	Puget Sound Pwr. & Lt. Co	134,000	80,429	1912	1916
Nisqually	Nisqually	Puget Sound	Washington	City of Tacoma	...	32,000	1912	1912
Cushman No. 1	Skokomish-N. Fk	Puget Sound	Washington	City of Tacoma	50,000	50,000	1926	1926
Cushman No. 2	Skokomish-N. Fk	Puget Sound	Washington	City of Tacoma	112,500	75,000	1931	1931
Corra Linn	Kootenay	Kootenay	Br. Columbia	West Kootenay Pwr. & Lt. Co	57,000	57,000	1932	1932
Upper Bonnington	Kootenay	Kootenay	Br. Columbia	West Kootenay Pwr. & Lt. Co	62,000	32,000	1907	1916
Lower Bonnington	Kootenay	Kootenay	Br. Columbia	West Kootenay Pwr. & Lt. Co	53,000	53,000	1925	1926
South Slocan	Kootenay	Kootenay	Br. Columbia	West Kootenay Pwr. & Lt. Co	75,000	75,000	1928	1929
Flathead	Flathead	Columbia	Montana	Montana Pwr. Co	234,000		Postponed	
Thompson Falls	Thompson	Columbia	Montana	Montana Pwr. Co	49,000	49,000	1916	1916
Little Falls	Spokane	Columbia	Washington	Wash. Water Pwr. Co	42,000	42,000	1910	1911
Long Lake	Spokane	Columbia	Washington	Wash. Water Pwr. Co	98,000	98,000	1916	1924
Grand Coulee	Columbia	Columbia	Washington	U. S. Govt	2,660,000	147,000	1937	...
Lake Chelan	Chelan	Columbia	Washington	Chelan Elec. Co	136,000	68,000	1927	1928
Rock Island	Columbia	Columbia	Washington	Puget Sound Pwr. & Lt. Co	210,000	84,000	1933	1933
American Falls	Snake	Columbia	Idaho	Idaho Pwr. Co	41,500	41,500	1912	1927
Bull Run "O"	Sandy	Columbia	Oregon	Portland Gen. Elec. Co	28,150	28,150	1912	1922
Bonneville	Columbia	Columbia	Oregon	U. S. Govt	688,000	114,600	1938	...
Oak Grove "P"	Clackamas	Columbia	Oregon	Portland Gen. Elec. Co	102,546	50,940	1924	1931
Cazadero "G"	Clackamas	Columbia	Oregon	Portland Gen. Elec. Co	20,442	20,442	1907	1910
West Linn (Clackamas Mill "A")	Willamette	Columbia	Oregon	Crown Williamette Paper Co	29,982	29,982	1889	1920
Ariel	Lewis	Columbia	Washington	Inland Pwr. & Lt. Co	126,000	63,000	1931	1931
Prospect No. 2	Rogue	Rogue	Oregon	Calif.-Oregon Pwr. Co	70,200	46,800	1928	1928

XIII—Middle North Pacific Drainage Area

Development	River	Drainage Basin	State or Province	Operating Company	Ultimate Horsepower	Hp	Year of Initial Operation	Year of Completion
Falls River	Falls	Skeena	Br. Columbia	Northern B. C. Pwr. Co. Ltd	32,000	4,000	1930	1930
Ocean Falls	Link	Link	Br. Columbia	Pacific Mills Ltd	...	30,000	...	...
Powell River	Powell	Powell	Br. Columbia	Powell River Co. Ltd	...	51,000	1910	1926
Lois River	Lois	Lois	Br. Columbia	Powell River Co. Ltd	50,000	24,800	1931	1931
Coquitlam-Buntzen	Burrard Inlet	Burrard Inlet	Br. Columbia	British Columbia Pwr. Corp	64,000	64,000	1904	1913
Bridge River	Bridge	Fraser	Br. Columbia	British Columbia Pwr. Corp	300,000	56,000	Postponed	
Stave Falls	Stave	Fraser	Br. Columbia	British Columbia Pwr. Corp	79,000	79,000	1912	1925
Ruskin	Stave	Fraser	Br. Columbia	British Columbia Pwr. Corp	188,000	47,000	1930	1930
Campbell	Campbell	Campbell	Br. Columbia	British Columbia Pwr. Corp	110,000	Postponed		
Jordan River	Jordan	Jordan	Br. Columbia	British Columbia Pwr. Corp	41,750	41,750	1911	1914

XIV—Hudson Bay Drainage Area

Development	River	Drainage Basin	State or Province	Operating Company	Ultimate Horsepower	Hp	Year of Initial Operation	Year of Completion
Island Falls	Churchill	Churchill	Saskatchewan	Churchill River Pwr. Corp	86,400	44,400	1930	1930
Ghost	Bow	Nelson	Alberta	Calgary Pwr. Co	55,000	38,000	1929	1929
Horseshoe Falls	Bow	Nelson	Alberta	Calgary Pwr. Co	20,000	20,000	1911	1911
Great Falls	Winnipeg	Nelson	Manitoba	Manitoba Pwr. Co	168,000	168,000	1928	1928
Pinawa	Winnipeg	Nelson	Manitoba	Winnipeg Elec. Co	37,800	37,800	1906	1906
Seven Sisters	Winnipeg	Nelson	Manitoba	North Western Pwr. Co	225,000	112,500	1931	1931
Slave Falls	Winnipeg	Nelson	Manitoba	City of Winnipeg Hydro Elec. System	96,000	24,000	1931	1931
Pointe du Bois	Winnipeg	Nelson	Manitoba	City of Winnipeg Hydro Elec. System	105,000	105,000	1911	1926
Smoky Falls	Mattagami	James Bay	Ontario	Spruce Falls Pwr. & Paper Co	75,000	75,000	1928	1931
Twin Falls	Abitibi	James Bay	Ontario	Abitibi Pwr. & Paper Co	30,000	30,000	1922	1930
Iroquois Falls	Abitibi	James Bay	Ontario	Abitibi Pwr. & Paper Co	28,000	28,000	1914	1917
Island Falls	Abitibi	James Bay	Ontario	Abitibi Pwr. & Paper Co	60,000	60,000	1925	1926
Abitibi Canyon	Abitibi	James Bay	Ontario	Hydro-Elec. Pwr. Comm	330,000	132,000	1933	1933

* The developments are classified in accordance with the following drainage areas, which may be identified on the accompanying map of the United States:

I North and Middle Atlantic
II South Atlantic and East Gulf of Mexico
III Great Lakes and St. Lawrence River
IV Upper Mississippi River
V Missouri River
VI Ohio River
VII Lower Mississippi River
VIII Western Gulf of Mexico
IX Gulf of California and Lower South Pacific
X Great Basin
XI Upper South Pacific
XII Lower North Pacific
XIII Middle North Pacific
XIV Hudson Bay

Table XII—Aggregate Horsepower Capacity of Turbines Installed or in Installation—Classified According to the Different Drainage Basins

	Canada and New Foundland	Mexico	United States	Total
I—North and Middle Atlantic Drainage Areas				
Deer Lake	156,000			156,000
St. John	80,000			80,000
Penobscot			42,500	42,500
Kennebec			68,000	68,000
Androscoggin			86,666	86,666
Saco			23,000	23,000
Merrimac			33,910	33,910
Connecticut			516,050	516,050
Housatonic			58,000	58,000
Hudson			298,500	298,500
Delaware			57,000	57,000
Susquehanna			820,213	820,213
Totals	236,000		2,003,839	2,239,839
II—South Atlantic and Eastern Gulf of Mexico Drainage Area				
James			20,200	20,200
Pee Dee			302,880	302,880
Santee			965,265	965,265
Savannah			294,000	294,000
Atetlamaha			93,000	93,000
Appalachicola			114,700	114,700
Alabama			583,000	583,000
Totals			2,373,045	2,373,045
III—Great Lakes and St. Lawrence River Drainage Area				
Lake Superior	186,000		69,700	255,700
Lake Huron	111,100		40,000	151,100
Lake Michigan			90,675	90,675
Lake Ontario	1,088,200		672,500	1,760,700
Oswegatchie			23,000	23,000
Raquette			37,700	37,700
Ottawa	1,072,000			1,072,000
Des Prairies	45,000			45,000
Richelieu	21,600			21,600
St. Francis	33,600			33,600
St. Maurice	779,500			779,500
St. Anne de Beaupré	24,000			24,000
Saguenay	755,000			755,000
St. Lawrence Proper	537,000		71,375	608,375
Totals	4,653,000		1,004,950	5,657,950
IV—Upper Mississippi River Drainage Area				
St. Croix			35,400	35,400
Chippewa			75,000	75,000
Wisconsin			41,150	41,150
Illinois			42,000	42,000
Mississippi			172,420	172,420
Totals			365,970	365,970
V—Missouri River Drainage Area				
North Platte			42,000	42,000
Osage			201,000	201,000
Missouri			315,000	315,000
Totals			558,000	558,000
VI—Ohio River Drainage Area				
Allegheny			34,000	34,000
Monongahela			96,000	96,000
New			172,000	172,000
Dix			32,724	32,724
Cumberland			35,510	35,510
Tennessee			986,690	986,690
Ohio			108,000	108,000
Totals			1,464,924	1,464,924
VII—Lower Mississippi River Drainage Area				
Arkansas			24,000	24,000
Red			79,000	79,000
Totals			103,000	103,000
VIII—Western Gulf of Mexico Drainage Area				
Grande		26,000		26,000
Tecolutla		168,000		168,000
Blanco		50,000		50,000
Totals		244,000		244,000
IX—Gulf of California Drainage and Lower South Pacific Area				
Colorado			588,420	588,420
Santiago		22,700		22,700
Lerma		65,000		65,000
Totals		87,700	588,420	676,120
X—Great Basin Drainage Area				
Great Salt Lake			151,000	151,000
Owens Lake			93,420	93,420
Totals			244,420	244,420
XI—Upper South Pacific Drainage Area				
Klamath			77,200	77,200
Sacramento			596,172	596,172
San Joaquin			1,047,070	1,047,070
Kern Lake			75,735	75,735
Los Angeles Aqueduct			158,200	158,200
Totals			1,954,377	1,954,377
XII—Lower North Pacific Drainage Area				
Puget Sound			648,819	648,819
Kootenay	217,000			217,000
Columbia			836,614	836,614
Rogue			46,800	46,800
Totals	217,000		1,532,233	1,749,233
XIII—Middle North Pacific Drainage Area				
Skeena	4,000			4,000
Link	30,000			30,000
Powell	51,000			51,000
Lois	24,800			24,800
Burrard Inlet	64,000			64,000
Fraser	182,000			182,000
Jordan	41,750			41,750
Totals	397,550			397,550
XIV—Hudson Bay Drainage Area				
Churchill	44,400			44,400
Nelson	505,300			505,300
James Bay	325,000			325,000
Totals	874,700			874,700

Table XIII—Aggregate Horsepower Capacity of Turbines Installed or in Installation in Different Drainage Areas of the North American Continent

Drainage Areas	Capacity in Horsepower: Canada and New Foundland	Mexico	United States	Totals
I.....North and Middle Atlantic	236,000		2,003,839	2,239,839
II....South Atlantic and Eastern Gulf of Mexico			2,373,045	2,373,045
III....Great Lakes and St. Lawrence River	4,653,600		1,004,950	5,657,950
IV....Upper Mississippi River			365,970	365,970
V.....Missouri River			558,000	558,000
VI....Ohio River			1,464,924	1,464,924
VII...Lower Mississippi River			103,000	103,000
VIII...Western Gulf of Mexico		244,000		244,000
IX....Gulf of California and Lower South Pacific		87,700	588,420	676,120
X.....Great Basin			244,420	244,420
XI....Upper South Pacific			1,954,377	1,954,377
XII...Lower North Pacific	217,000		1,532,233	1,749,233
XIII..Middle North Pacific	397,550			397,550
XIV..Hudson Bay	874,700			874,700
Totals	6,378,250	331,700	12,193,178	18,903,128

Table XIV—Aggregate Horsepower Capacity of Turbines Installed or in Installation in the Main Drainage Basins of the North American Continent

Drainage Basin	Horsepower Capacity	Drainage Basin	Horsepower Capacity
St. Lawrence River	5,657,950	Puget Sound	648,819
Mississippi River	2,443,894	Connecticut River	516,050
Columbia River	1,053,614	Nelson River	505,300
San Joaquin River	1,047,070	James Bay	325,000
Santee River	965,265	Pee Dee River	302,880
Susquehanna River	820,213	Hudson River	298,500
Sacramento River	596,172	Savannah	294,000
Colorado River	588,420		
Alabama River	583,000	Total	16,646,147

Report of the Board of Directors

The board of directors of the American Institute of Electrical Engineers presents herewith to the membership its fiftieth annual report, for the fiscal year ending April 30, 1934. A general balance sheet showing the condition of the Institute's finances on April 30, 1934, together with other detailed financial statements, is included herein. This report contains a brief summary of the principal activities of the Institute during the year, more detailed information having been published from month to month in ELECTRICAL ENGINEERING.

Fiftieth Anniversary of A.I.E.E.

THE BOARD of directors approved recommendations of the publication committee and the committee on coördination of Institute activities, and provided for the observance of the fiftieth anniversary of the organization of the Institute, on May 13, 1884, by the publication of a special issue (May 1934) of Electrical Engineering and by the presentation, through the corresponding Section, of a suitable type of membership badge and certificate to each surviving Charter Member still on the membership list. It authorized the appointment by the President of the fiftieth anniversary committee, which coöperated with the publication committee in the preparation of the special issue of Electrical Engineering, and has arranged for addresses commemorating the anniversary to be given at the summer convention by Past-President William McClellan and by Dr. William E. Wickenden.

Directors' Meetings

The board of directors held 5 meetings, 4 in New York, and 1 in Chicago, Ill. The executive committee held meetings in December and March, substituted for the regular meetings of the board, and acted upon various matters between board meetings.

Information regarding the more important activities of the Institute which have been under consideration by the board of directors, the committees, and the various officers is published each month in the section of Electrical Engineering devoted to "News of Institute and Related Activities."

President's Visits

President Whitehead attended the winter convention and visited a large number of the Sections.

The following is a list of places visited: Philadelphia, and Pittsburgh, Pa.; Washington, D. C.; Kansas City, Mo.; Omaha, Neb.; Denver, Colo.; Salt Lake City, Utah; Los Angeles, and San Francisco, Calif.; Portland, Ore.; Seattle, and Spokane, Wash.; Vancouver, B. C., and Toronto, Ont., Canada; Bozeman, Mont.

An invariable feature of these visits was a conference with the executive committee and other prominent members of the respective Sections, in which President Whitehead reviewed recent matters considered by the board of directors and other important questions still before them. Emphasis was laid on the financial condition of the Institute as related to losses of membership and the importance of support to the active membership campaign now under way. Attention was also devoted to the numerous questions which have recently arisen concerning the profession of engineering as a whole, but which do not fall within the sphere of the normal functions of the Institute. President Whitehead described the several existing agencies which have already been set up in conjunction with the other founder societies for handling questions of this character, dwelling especially on the purposes of American Engineering Council, the Engineers' Council for Professional Development, United Engineering Trustees, Inc., and other similar joint organizations. These reviews brought out much profitable discussion, and it was extremely satisfactory to find that there is little or no difference of opinion that the strength of the Institute rests largely in its adherence to its traditional ideals and functions, and that our participation in discussion of questions of controversial and semi-political character should be made through joint agencies with other branches of the profession, such as those referred to.

These business meetings with the local Sections were usually held either before or during a dinner tendered the President by the Section. Thereafter adjourning to another hall and a much larger meeting, Doctor Whitehead delivered a lecture entitled "Liquid Dielectrics," reporting some of the results of recent research in this field. The lecture was usually followed by a profitable discussion. In several Sections, Doctor Whitehead also addressed student Branches of the Institute and in such places faculties and student bodies contributed substantially to the success of the meetings.

Doctor Whitehead is especially appreciative of the many pleasures and courtesies of social character extended him everywhere. The board of directors wishes to add here its own appreciation and thanks to those of President Whitehead for his cordial reception everywhere by the Sections.

In May and June, President Whitehead's visits will include the summer convention in Hot Springs, Va., and other Sections.

Meetings

Two national conventions and one District meeting were held during the year, and a brief report on each follows.

Annual Meeting

The annual business meeting of the Institute was held at the Edgewater Beach Hotel, Chicago, Ill., Monday morning, June 26, 1933, as part of the opening session of the annual summer convention. The annual report of the board of directors for the fiscal year ending April 30, 1933, was presented in abstract, and the committee of tellers reported upon the election of officers for the administrative year beginning August 1, 1933. President-elect Whitehead responded with a brief address.

Election of Honorary Members

Six distinguished members of the Institute were elected Honorary Members by the board of directors on May 22, 1933: W. L. R. Emmet, G. A. Hamilton, A. E. Kennelly, R. A. Millikan, E. W. Rice, Jr., and Edward Weston. Announcement of their election was made, certificates were presented, and each who was present responded briefly, during the opening session of the summer convention, Monday morning, June 26.

Summer Convention

The forty-ninth annual summer convention was held at Chicago, Ill., June 26–30, 1933. Thirty-three papers were presented at 6 technical sessions. The annual conference of officers, delegates, and members, under the auspices of the Sections committee and the committee on student Branches, was held on Monday, June 26, and Tuesday, June 27, and 60 Section delegates, 3 District secretaries, and 6 counselor delegates were present. The entertainment features included golf and tennis tournaments, a dinner-dance, and various trips. The Lamme Medal for 1932 which was awarded to Dr. Edward Weston was presented during the opening session, being received, in the absence of Dr. Weston, by his son Edward F. Weston. 968 members and guests attended the convention.

Engineers' Week

Many engineering societies held their annual conventions in Chicago during the week of June 26–30, 1933, which was designated as Engineers' Week at the Century of Progress Exposition. The week was notable for the large number of joint meetings held by the various engineering and scientific societies. Wednesday, June 28, was devoted to joint activities of interest to members of practically all societies.

Winter Convention

The twenty-second winter convention was held in New York, January 23–26, 1934. Fifty-three papers were presented at 11 sessions. At an evening session, the Edison Medal was presented to Dr. Arthur E. Kennelly. Numerous inspection trips, a demonstration of the transmission and reproduction of speech and music in auditory perspective, a smoker, and a dinner-dance were held. The registration was 1,227.

District Meeting

Information on the District meeting held is given in Table I.

Table I—District Meeting

District No.	Location	Dates	Papers	Registration
1	Schenectady, N. Y.	May 10–12, 1933	15	431

Thirteen Student papers were presented.

Sections

Practically all Sections carried on a normal amount of activity, and nearly all of them agreed to keep their expenses for the present budget year at least 20 per cent below the maximum amounts that would be available under the by-laws, as suggested by the board of directors. The total number of meetings held was only slightly below the total of last year.

President Whitehead visited many of the Sections (see heading "President's Visits"), and will visit others in May.

The 4 groups of the New York Section and the power group of the Chicago Section continued a normal amount of activity and their meetings have been very popular among the members.

In connection with the work of the national membership committee, many of the Sections have made special efforts to retain their members and to encourage those who had been forced to relinquish membership to be reinstated.

The New Orleans Section was organized in January with the entire state of Louisiana as its territory. This brought the total number of Sections to 61.

With the adoption of a publication plan under which members and enrolled students are receiving in Electrical Engineering practically twice the amount of technical material previously supplied, it was necessary to reduce the news content. The publication committee, therefore, decided to discontinue the publication of detailed reports on local meetings, but to provide for suitable news items on Section and Branch activities, the details to be developed between the publication committee and the Sections committee and the committee on student Branches, respectively.

The fiftieth anniversary committee suggested that each Section and each Branch hold a meeting during May for appropriately observing the fiftieth anniversary of the organization of the Institute. Many Sections and Branches are planning such meetings and making special arrangements for the presentation of interesting historical information concerning the development of the Institute.

Student Activities

Nearly all Branches continued their activities in a normal manner, and the total number of meetings was almost equal to that for last year. Many of them have continued to place strong emphasis upon talks by students.

Upon the recommendations of the counselor delegates at the summer convention, the conference of officers, delegates, and members recommended to the board of directors the adoption of provisions for the enrollment in the Institute of evening students in electrical engineering in institutions offering evening courses considered by the committee on student Branches to meet the requirements outlined in the by-laws and for the organization of such evening students for Branch activities. Amendments to the by-laws to provide for such enrollment and for the organization of evening divisions of the corresponding student Branches were adopted, and the committee on student Branches approved the enrollment of evening students of the following institutions: Polytechnic Institute of Brooklyn, University of Cincinnati, Cooper Union, George Washington University, College of the City of New York, and New York University.

In adopting the budget for the present year, the board of directors provided an allowance for traveling expenses for a District conference on student activities in each District having a committee on student activities.

Nearly 50 per cent of the enrolled students whose periods of enrollment expired on April 30, 1934, applied for admission as Associates.

New Branches were organized at South Dakota State College, Brookings, So. Dakota, and Villanova College, Villanova, Pa., bringing the total number to 113.

See the last 2 paragraphs under the heading "Sections" which contain material concerning Sections and Branches.

Section and Branch Statistics

Data on the Sections and Branches are given in Table II.

Table II—Section and Branch Statistics

	For Fiscal Year Ending			
	April 30, 1928	April 30, 1930	April 30, 1932	April 30, 1934
Sections				
Number of Sections	52	56	60	61
Number of Section meetings held	431	480	497	472
Total attendance	64,276	84,615	105,325	73,271
Branches				
Number of Branches	96	106	109	113
Number of Branch meetings held	915	1,009	1,135	1,015
Total attendance	44,334	50,401	54,197	41,772

Technical Program Committee

In addition to its routine functions the technical program committee has devoted a good portion of its time to analysis of its duties, division of work between technical committees, and like matters with a view toward achieving better balance among technical activities. It has obtained working agreements as to division of work between technical committees, better delineation of scopes of individual committees, and in general a more harmonious and efficient functioning of this portion of Institute work.

Analysis of the character of material presented has been continued with the result that some of the committees which previous analysis showed to lag in the amount of material presented have been encouraged to greater activity. In the field of electrochemistry and electrometallurgy a symposium on electric furnaces was held during the winter convention, which brought out 7 valuable papers and considerable discussion on this subject. In the field of education a session also was held which proved to be of broad general interest.

The committee has reviewed 175 papers during the year. Of this number, 101 were presented at the 2 national conventions and 1 District meeting held during the year and 90 of these have been recommended for publication in the TRANSACTIONS. Of the remainder, 74 papers, 26 have been published in ELECTRICAL ENGINEERING and some of these have been scheduled for future meetings, while others are awaiting publication; a few have been returned to the authors. The total attendance for the 3 meetings during the year was 2,626, 9.9 per cent less than the total attendance of the previous year, during which 2 more meetings were held. The attendance at the winter convention alone was 1,227, representing an increase of $11^1/_2$ per cent over the attendance for the same convention the previous year. Details regarding the attendance and number of papers presented at each convention are given in Table III.

The committee has fostered the attempt to achieve short and interesting presentation of papers, thus allowing more time for discussion. Presentation of papers by title only has been tried experimentally with quite good results. The papers thus presented were all published previously and presumably had been read by practically every one in attendance. Stricter adherence to time limit on discussions was also urged with the result that the conduct of meetings is approaching a smoother performance.

The new publication policy of the Institute has resulted in a material change in scheduling the receipt and publication of papers. The committee

Table III—Attendance and Numbers of Papers Presented April 30, 1933, to April 30, 1934

Meetings	No. Papers Presented	No. Pages Printed	No. Papers Recommended for TRANS.	No. of Sessions	Attendance
National Conventions					
Summer convention, Chicago, Ill., June 26–30, 1933	33	226	31	10*	968
Winter convention, New York, January 23–26, 1934	53	337	49	11	1,227
Total	86	563	80	21	2,195
District Meetings					
North Eastern District, Schenectady, N. Y., May 10–12, 1933	15	62	10	4	431
Grand total	101	625	90	25	2,626

* Includes 4 joint meetings with other societies.

has been able to offer the publication committee complete coöperation and the transition from the old basis to the new is being accomplished with no major difficulties.

The code of the meetings and papers committee has been revised to conform to the recent changes in routine and procedure and will be reissued as the code of the technical program committee.

Suggestions from individuals, Sections, Districts, and other committees have been received, examined, and, if possible, incorporated within the activities of the committee.

Acknowledgment by the committee for coöperation in handling its complex interrelationships is due to authors, technical committee members, reviewers, the headquarters staff, and to the committee's permanent secretary.

Publication Committee

The completion of further studies of the many problems involved in the production of the Institute's publications made information available upon the basis of which the publication committee early in the fiscal year recommended extensive and important changes in the publication policy and procedure. Recognizing the pressing necessities of the present economic situation, and recognizing also the desirability of improving the Institute's publication service to its individual members, the committee recommended the elimination of the costly duplication in publication represented by the traditional issuance of individual pamphlet copies of technical papers, and recommended the consolidation of the monthly and the quarterly publications.

The several related proposals were discussed at length at the conference of officers, delegates, and members held in connection with the forty-ninth annual summer convention in Chicago, and by that body were recommended favorably to the board of directors. Accordingly, at its regular meeting August 8, 1933, the board of directors ratified the proposals involved in the new publication policy and recommended their immediate application, with the understanding that further details would be developed by the publication committee. The details involved have been dealt with extensively in Electrical Engineering (first and second covers, September 1933; p. 665, October 1933; p. 793, November 1933) and consequently they will be only summarized here.

Electrical Engineering will continue to be published monthly as the Institute's official technical organ, becoming the primary publication by virtue of enlargement to include the full text of all recommended A.I.E.E. papers, and the acceptable discussions thereon. The quota of special articles and other features that have proved so popular since January 1931 is scheduled to be maintained as previously established. Some routine departmental material that proved to be of but little value and only limited interest has been omitted or reduced to a conciseness commensurate with its usefulness. Thus every member of the Institute will receive month-by-month in a timely fashion all the Institute's technical material in addition to other material of current interest. This is a further step in the development of an adequate publication policy undertaken seriously by the publication committee in 1929, and continuously under consideration and development since that time.

The Transactions, previously issued quarterly, now are to be issued at the close of each calendar year as an annual volume embracing the contents of the 12 issues of the monthly publication for that year. Because this annual volume will be a duplicate publication and will be desired only by a minority of the membership, a nominal subscription price ($4 yearly to members) is being charged for a cloth bound volume estimated to contain about 1,400 pages.

Technical papers and discussions, to a large degree if not entirely, will be released for publication in Electrical Engineering immediately upon the logical completion and technical review of the manuscripts, instead of having the release of contemporary manuscripts controlled artificially by some advance meeting date. Because of this improved general distribution of technical papers, the production and free distribution of separate pamphlet copies of technical papers has been discontinued.

For economic reasons the application of the unified plan was undertaken in the fall and winter of 1933–4. This rapid changeover caused several new, although temporary, problems to be involved, such as oversize monthly issues of Electrical Engineering. However, both the Institute membership and the Institute budget have profited by the advanced changeover. It is contemplated that the program will be in full and smooth operation by the close of the current calendar year, if not before.

In commemoration of the founding of the Institute May 13, 1884, Electrical Engineering for May 1934 was enlarged and issued as an Anniversary number, reflecting the highlights of Institute history.

Standards

During the past year, since April 30, 1933, it has been found necessary to call only 3 meetings of the standards committee. The time of the committee at those meetings was devoted almost entirely to matters of organization of committees and coordination of projects in hand or proposed.

Due to the many changes which have occurred in both membership of the Institute and the personnel of companies and organizations, a considerable number of new appointments of A.I.E.E. representatives on various sectional committees of the American Standards Association and on standardizing committees of other organizations have been made.

Several new propositions for standardization have been presented to the committee for consideration and recommendation as to disposition. Among these may be noted the following: Modification of standards for temperature limits of insulation; standardization of depreciation in electrical machinery and apparatus; and development of a color code for control wiring. In addition, a number of

suggestions for revision of existing A.I.E.E. standards and American standards were received and transmitted to the committees concerned.

Seven standards have received the approval of the A.S.A. either as "American Standards" or "Tentative Standards." Four of these were standards appearing in the A.I.E.E. series and 3 were developed by a sectional committee of which the Institute was a joint sponsor. The standards approved were as follows: Constant Current Transformers; Graphical Symbols for Electric Power and Wiring, for Radio, and for Electric Traction, including Railway Signaling; Capacitors; Electric Arc Welding Apparatus; Resistance Welding Apparatus. In November 1933, the sectional committee on Rotating Electrical Machinery issued its first report on "Proposed American Standards for Rotating Electrical Machinery." This report, when it eventually reaches the status of a standard, will replace the 5 present A.I.E.E. rotating machinery standards which were used largely as the basis of the report.

U.S. National Committee of the I.E.C.

The work of the International Electrotechnical Commission has been somewhat hampered during the past year by world economic conditions. Only one meeting of the U.S. National Committee has been necessary to take care of participation by the United States in I.E.C. work.

Progress was made on specific technical projects during the year as follows:

1. *International Electrotechnical Vocabulary.* A meeting of the international advisory committee which has in preparation a comprehensive electrotechnical vocabulary in French and English was held in Paris in October. It is now proposed that the French portion of the vocabulary will be prepared first and it is hoped that it will be possible to submit this part to the I.E.C. within the next year. After this is done the English edition will be prepared through coöperation with the British and U. S. National Committees.

2. *Electric and Magnetic Magnitudes and Units.* A meeting of this section of advisory committee No. 1 on nomenclature was held in Paris in October under the chairmanship of Dr. A. E. Kennelly. Recommendations in regard to unit names, unit symbols, definitions of the cgs units and the conventional direction of inductively reactive power in diagrams were arrived at and will be submitted later to all of the national committees of the I.E.C. A complete statement of the status of this work is contained in Electrical Engineering for March 1934, p. 402–5.

3. *Electric Traction Equipment.* At a meeting of the committee of action of the I.E.C. held in Paris in October it was decided to publish the revised rules for electric traction equipment. Such publication was objected to by the U.S.N.C. on the grounds that the rules as proposed were contrary to the best engineering opinion in this country and would result in unfavorable changes in both cost and efficiency. The first page of the publication contains a statement to the effect that the rules have been objected to by the U.S.N.C. The document is designated as "I.E.C. Publication No. 48—Rules for Electric Traction Motors" (1st edition 1933).

During the year technical advisors were appointed for the 2 advisory committees organized the preceding year, F. M. Farmer as technical adviser on the subject of electric cables (I.E.C. committee No. 20) and Dr. George W. Vinal as technical adviser on accumulator batteries (I.E.C. committee No. 21).

The meeting of advisory committee No. 19 on internal combustion engines, scheduled for last September in this country, was not held because of the fact that so many of the foreign national committees found it impossible to send delegates.

The plenary meeting of the I.E.C. which had been scheduled for 1934 in Prague has been postponed until 1935. No definite time has been set and no place decided upon but the suggestion has been made that it would be well to hold the meeting in Brussels during the universal exhibition which will take place in 1935.

Coördination Committee

In accordance with past practice, the committee corresponded with District and Section officers to obtain their views regarding any national conventions and District meetings desired in their respective Districts during the calendar year 1935. On account of economic conditions, the committee recommended to the board of directors, at its meeting held on January 22, 1934, that the adoption of a schedule of 1935 meetings be postponed to the May meeting of the board, and this recommendation was approved.

The committee considered and reported to the board of directors upon various matters which had been referred to it.

Committee on the Economic Status of the Engineer

The activities of this committee were largely referred to and handled by the Institute's delegation on Engineers' Council for Professional Development, which was organized in 1932.

Committee on Safety Codes

No meetings of the committee were called this year, as no matters were presented either from within the committee or from outside organizations to warrant calling a meeting.

The Institute was represented by delegates from the committee on safety codes at the meetings of the National Fire Waste Council, in Washington, and the National Fire Protection Association, in Milwaukee.

The chairman of the committee worked with the National Safety Council on their recently revised "Safe Practices Pamphlet No. 29 on Electrical Equipment in Industrial Plants," and carried on correspondence in connection with arranging for speakers for the annual safety congress of the National Safety Council held in Chicago in 1933.

The chairman of the committee on safety codes of the A.I.E.E. has continued to function as the chairman of a special committee of the electrical committee of the National Fire Protection Association on the use of bare neutral in interior wiring systems. It was desirable to have an engineering representative as chairman of this special committee and, if possible, an individual with central station, manufacturing, and actual wiring experience. This subject has been an active one and has involved considerable correspondence and activity for the

chairman and the special committee. The subject is still active and continuing. In its ramifications it involves the function of water mains, and services, in connection with the grounding of distribution and house wiring systems. Considerable material has been gathered, but no report has as yet been rendered.

Technical Committees

The technical committees continued their activities in the stimulation of the preparation of desirable papers in their respective fields and in the review of papers submitted to the Institute for presentation and publication. Information on meetings, papers, and publications is given on other pages of this report.

Membership Committee

The membership committee with a complete District and Section organization has been working diligently to obtain applications for membership, to bring Students into Associate membership, and to urge and help members to reinstatement. The results are shown in the accompanying tables.

Table IV gives the annual membership statistics in the usual form.

Table IV—Membership Statistics for the Fiscal Year Ending April 30, 1934

	Honorary	Fellow	Member	Six-Year Associate	Associate	Total
Membership on April 30, 1933	9	729	3,864	6,671	5,747	17,020
Additions:						
Transferred	6	25	134	750		
New members qualified		1	46	11	654	
Former members reinstated		1	15	48	21	
Total	15	756	4,059	7,480	6,422	18,732
Deductions:						
Died		26	34	29	13	
Resigned		3	77	315	188	
Transferred		3	25	126	761	
Dropped		10	230	861	801	
Membership on April 30, 1934	15	714	3,693	6,149	4,659	15,230

Table V shows the number of applications received from enrolled Students and from all others during each of the past 4 fiscal years. Fewer Students' applications are being received for Associate membership, and the number of applications received from all others during the past year was larger than for the preceding year.

Table V—Number of Applications Received From Enrolled Students and From All Others

Year Ending	From Students	From All Others	Total
April 30, 1934	467	498	965
April 30, 1933	674	305	979
April 30, 1932	779	612	1,391
April 30, 1931	533	964	1,497

Table VI shows that the number of enrolled Students has been decreasing. It is of major importance to the Institute that the Student enrollment be maintained for future membership. While Student enrollment is under the auspices of the committee on Student Branches, the membership committee is responsible for obtaining applications from enrolled Students for admission to the Associate grade.

Table VI—Number of Enrolled Students

April 30, 1934	3,186 (1,548)
April 30, 1933	3,260 (1,494)
April 30, 1932	3,700 (1,624)
April 30, 1931	3,813 (2,218)

(Following the number of Students reported for April 30th of each year is indicated, within parentheses, the number of new applications received during that year; the difference between this number and the reported total, of course, reflects the number of renewals of Student enrollment for the corresponding period.)

Considerable effort of the membership committee has been devoted to encouraging and helping members in arrears for dues, and thereby subject to suspension, to be reinstated to active membership. The figures of Table VII show the results of this effort. In these results, the committee feels there is cause for satisfaction.

Table VII—Number of Members in Section Territory Reinstated

August 1, 1933, to April 30, 1934	603
Year beginning August 1, 1932	277
Year beginning August 1, 1931	327
Year beginning August 1, 1930	375

The membership committee has received verbal and written communications urging leniency in carrying members faced with unfavorable financial circumstances. Table VIII shows the figures in this regard.

Table VIII—Membership of the Institute, April 30, 1934

Of the 15,230 membership reported for April 30, 1934, 11,028 are fully paid to April 30, 1934. The balance of 4,202 are divided into the following groups:

1. Members owing dues to May 1, 1933.	
Total number of members who have not acted upon resolution of board of directors adopted in January 1934 providing an extension of time for payment of these dues (including 826 members of 6 years' standing or longer who were entitled, upon application, to dues cancellation if unemployed during corresponding fiscal year)	1,874
Total number of members who obtained dues cancellation to May 1, 1933, because of unemployment reasons (80), or who have received an extension of time (48), but who have not yet renewed active membership on pro rata basis for current year, as provided in resolution of board of directors adopted in January 1934	128
	2,002
2. Members owing dues to May 1, 1934	2,200
(During the period May 1 to 22, 1934, 353 members have paid dues to May 1, 1934, reducing the total to 1,847.)	

The large number of letters sent out by headquarters staff pursuant to the resolutions of the board of directors, together with many answers from members afford convincing proof that the attitude has been liberal. If occasions arise where it apparently has not seemed liberal, they are, undoubtedly, due to misunderstandings.

As a comparison, the figures of Table IX are of interest:

Table IX—Memberships Fully Paid

	Membership as of April 30	Number of Members Fully Paid as of April 30	Per cent Fully Paid
1934	15,230	11,028	72.4
1927 (year of maximum membership)	18,344	16,247	88.5

Deaths

The following deaths have occurred during the year:

Fellows: Harold DeForest Arnold, Ernest J. Bechtel, Frederick N. Bosson, Byron T. Burt, Alexander Churchward, Charles F. Conn, Harry C. Cushing, Jr., Minor M. Davis, Clarence E. Doolittle, Giuseppe Faccioli, William J. Hammer, William S. Lee, James Lyman, Kempster B. Miller, John H. Morecroft, Everett Morss, Niels L. Mortensen, Farley Osgood, Frank W. Peek, Jr., Norman N. Ross, Edson O. Sessions, H. A. Sinclair, George O. Squier, J. Franklin Stevens, Calvert Townley, George M. Yorke.

Members: Albert E. Alkins, Frank H. Bernhard, Lee Boyer, Burton H. Brooks, Arthur A. Brown, William A. Bucke, T. Herbert Clegg, G. Herbert Condict, Harry A. Curtis, Henry H. Cutler, Harry T. Edgar, Augustine R. Everest, Charles L. Fortier, Albert L. Harvey, Murray J. Idail, Herbert E. Kaighn, Louis F. Leurey, Cyril F. Mackness, Walter C. Mangels, Norman Marshall, George J. Newton, C. W. Nitschke, Francis L. O'Bryan, Joseph D. Peters, William B. Potter, Thorburn Reid, Charles H. Schum, Robert Shand, Carleton W. Smith, Harold W. Smith, John E. Sumpter, Charles S. Thompson, Roberto J. Urie, George C. Ward.

Associates: R. Narayana Aiyangar, Charles G. Beckwith, John C. Benjamin, Norman McD. Crawford, Herbert H. Dewey, Paul Dewitt, Jetha N. Diwan, William A. Ferguson, James G. Finley, Leon H. Frank, Otto T. Gierisch, Maurice Grunfield, J. Henry Hackett, Grenville A. Harris, Herman T. Hauser, Paul H. Jaehnig, E. C. Joho, Charles F. Kaesemeyer, Shizuo Katoh, William W. Ker, Myles B. Lambert, William F. Lamme, Charles V. Lenehan, Robert Lindsay, Marion B. Lines, Daniel R. Lyden, George B. McElheny, Charles A. McGeehan, Charles F. Medbury, Edward A. Mellinger, Veator D. Mendenhall, Vance W. Miller, Edward F. Morrill, Edson L. Morris, Ord Myers, M. Alfonso Porras, Frederick J. Rasmussen, Walter D. Ryan, Clare N. Stannard, Horace W. Steinhoff, Emanuel W. Sundberg, Paul S. Sussan.

Board of Examiners

The board of examiners held 9 meetings during the past year, averaging about 2.5 hr, and considered 2,277 cases, divided as shown in Table X.

Table X—Applications for Admission and Transfer

Applications for Admission:		
Recommended for grade of Associate	771	
Not recommended	5	
		776
Recommended for grade of Member	48	
Not recommended	12	
		60
Recommended for grade of Fellow	1	
Not recommended	2	
		3
Recommended for enrollment as Students		1254
Applications for Transfer:		
Recommended for grade of Member	154	
Not recommended	3	
		157
Recommended for grade of Fellow	25	
Not recommended	2	
		27
		2277

Institute Prizes

Five national prizes and 9 District prizes for papers presented in 1932 were announced on p. 424 of the June 1933 issue of ELECTRICAL ENGINEERING. The national prizes were presented at the summer convention in Chicago, and the District prizes were presented at various meetings in the respective Districts.

Scholarships

The governing bodies of Columbia University have placed at the disposal of the Institute each year a scholarship in electrical engineering for each class. The awards are made annually by an Institute committee. Each scholarship pays $350 toward annual tuition, with provision for reappointment.

Complete details governing prizes and scholarships may be obtained by applying to the national secretary of the Institute.

Edison Medal

The Edison Medal, founded by associates and friends of the late Thomas A. Edison, is awarded annually by a committee consisting of 24 members of the Institute "for meritorious achievement in electrical science, electrical engineering, or the electrical arts." The medal for 1933 was awarded to Dr. Arthur E. Kennelly, "for meritorious achievements in electrical science, electrical engineering, and the electrical arts as exemplified by his contributions to the theory of electrical transmission and to the development of international electrical standards." The medal was presented at the winter convention of the Institute, January 24, 1934.

John Fritz Medal

The John Fritz Medal board of award, which is composed of representatives of the national societies of civil, mining, mechanical, and electrical engineers, awarded the thirtieth medal to John Ripley Freeman, posthumously.

Lamme Medal

The Lamme Medal was founded as a result of a bequest of the late Benjamin G. Lamme, chief engineer of the Westinghouse Electric and Manufacturing Company, who died on July 8, 1924. The bequest provides for the award by the Institute of a gold medal (together with a bronze replica thereof) annually to a member of the A.I.E.E. "who has shown meritorious achievement in the development of electrical apparatus or machinery" and for the award of 2 such medals in some years if the accumulation from the funds warrants.

The Lamme Medal committee of the Institute awarded the sixth (1933) Lamme Medal to Dr. Lewis B. Stillwell, "for his distinguished career in connection with the design, installation, and operation of electrical machinery and equipment." Arrange-

ments are being made for the presentation of the medal at the annual summer convention at Hot Springs, Va., June 25–29, 1934.

Alfred Noble Prize

This prize, established in 1929, consists of a certificate and a cash award of $500 from the income from a fund contributed by engineers and others to perpetuate the name and achievements of Alfred Noble, past-president of the A.S.C.E. and of the Western Society of Engineers. It is made to a member of any of the coöperating societies, A.S.C.E., A.I.M.E., A.S.M.E., A.I.E.E., or W.S.E., for a technical paper of particular merit accepted by the publication committee of any of these societies, provided the author, at the time of such acceptance, is not over 30 years of age. The third award (1933) was made to C. Maxwell Stanley.

Commission of Washington Award

This award may be made annually "to an engineer whose work in some special instance, or whose services in general have been noteworthy for their merit in promoting the public good," by a committee composed of 9 representatives of the Western Society of Engineers and 2 each from the A.S.C.E., the A.I.M.E., the A.S.M.E., and the A.I.E.E.

Iwadare Foundation Committee

As this is the first report of the Iwadare Foundation committee, an outline of its work since its appointment and a brief statement of its functions are included.

In 1929 Mr. K. Iwadare of Japan established and generously endowed a Foundation under the trusteeship of the Denki-Gakkwai (The Institute of Electrical Engineers of Japan) with a 2-fold purpose:

1. To provide from the income the means for enabling promising Japanese students to reside in the United States for a period of one year for the purpose of carrying on studies in electrical engineering colleges, the plants of electrical industries, and government institutions; and

2. To provide from the income the means for bringing to Japan from time to time noted American electrical engineers to deliver a series of lectures on American advances and practices in the electrical arts.

As the Japanese Institute naturally looked to our Institute for guidance in carrying out this program in the United States, the Iwadare Foundation committee was appointed by the President of the American Institute of Electrical Engineers in December 1931, to assist the Japanese Institute in carrying out the provisions of the Iwadare Foundation.

The committee appointed consisted of F. B. Jewett, chairman, W. I. Slichter, and Gerard Swope. This committee served until August 1, 1933, at which time Professor Slichter's term expired. At that time, Dr. C. E. Skinner was appointed to this committee, and the present membership consists of F. B. Jewett, chairman, Gerard Swope, and C. E. Skinner.

The first purpose of the Iwadare Foundation has been handled in the main by the Japanese Institute of Electrical Engineers. From time to time, recipients of such fellowships have come to our country and, under the guidance of our national secretary, have been enabled to carry on work in the field of their choice. Five Fellows so far have visited this country, namely:

Masaharu Hoshiai, Assistant Professor of Electrical Engineering at Tokyo Imperial University.

Takeo Akahira, Research Engineer of the Institute of Physical and Chemical Research.

Tomoyoshi Hirota, Assistant Professor of Electrical Engineering at Waseda University.

Kichizo Sakakibara, Electrical Engineer.

Shintaro Uda, Assistant Professor of Electrical Engineering at Tohoku Imperial University.

The sixth Fellow,

Y. Takahashi of the Meidensha Elec. Works, Tokyo (Part-time lecturer at Imperial University)

called at Institute headquarters on April 25, 1934.

The second purpose of the Iwadare Foundation has not so far worked out entirely as intended. Dr. A. E. Kennelly of Harvard University was invited to lecture in Japan before the Iwadare Foundation committee was appointed. He went to Japan late in 1931. Since his visit, largely due to the depression, no other lecturer has visited Japan under a grant from this Foundation. The late General J. J. Carty, at one time vice-president of the American Telephone and Telegraph Company, and Dr. Frank J. Sprague, president of the Sprague Safety Control and Signal Corporation, both past-presidents of the American Institute of Electrical Engineers, and E. M. Herr, formerly president of the Westinghouse Electric and Manufacturing Company, had each accepted an invitation to go to Japan, but circumstances arose which precluded their final acceptance. A few other candidates of suitable caliber from industrial organizations, solicited by your committee, could not at the time leave the United States.

Last fall Dr. C. E. Skinner, past-president of the American Institute of Electrical Engineers, on the recommendation of your committee, accepted an invitation from the Japanese Institute to be the next lecturer from the United States, and he is now in Japan and plans to remain there during April 1934.

The Japanese Institute of Electrical Engineers has requested the American Institute through your committee to select another lecturer for next fall. Although it is the desire of the people in Japan in general to select 2 representatives from industry to one from university circles, it may be impossible this year to adhere strictly to this preference and it may be that your committee will make the next selection from university circles, although if possible the next appointee will be from the industrial field.

Advisory Committee to New York Museum of Science and Industry

The committee, during the past year, has been in conference with Dr. C. R. Richards, director of the

New York Museum of Science and Industry, and has made a survey of the exhibits of the Museum, particularly with reference to the developments in the generation, distribution, and application of electricity.

Employment Service

The Institute coöperates with the national societies of civil, mining, and mechanical engineers in operation of the Engineering Societies Employment Service with its main office in the Engineering Societies Building, New York. Offices are operated in Chicago and San Francisco also. In addition to the societies named, others coöperate in certain of the offices as follows: New York—Society of Naval Architects and Marine Engineers; Chicago—Western Society of Engineers; San Francisco—California Section of the American Chemical Society, and the Engineers Club of San Francisco.

The New York office has coöperated closely with the Professional Engineers Committee on Unemployment which was organized in the fall of 1931 by the local Sections of the A.S.C.E., A.I.M.E., A.S.M.E., and A.I.E.E.

The service is supported by the joint contributions of the societies and their individual members who are benefited. As in the past, it consists principally in acting as a medium for bringing together the employer and the employee. In addition to the publication of the employment service announcements monthly in Electrical Engineering, weekly subscription bulletins are issued for those seeking positions.

An analysis of this employment service is given in Table XI.

Table XI—Analysis of Employment Service

	Men Registered				Men Placed			
Month	New York	Chicago	San Francisco	Total	New York	Chicago	San Francisco	Total
1933								
May	122	46	66	234	35	35	28	98
June	156	33	52	241	50	12	25	87
July	128	51	57	236	33	9	22	64
August	144	45	74	263	42	11	21	74
September	126	43	46	215	48	4	10	62
October	100	24	31	155	62	8	21	91
November	77	17	26	120	63	11	44	118
December	75	4	38	117	52	5	25	82
1934								
January	67	1,002	44	1,113	60	644	17	721
February	66	74	37	177	38	80	9	127
March	81	33	69	183	48	23	10	81
April	93	49	48	190	54	15	17	86
Total	1,235	1,421	588	3,244	585	857	249	1,691

American Engineering Council

The "object" of the American Engineering Council, as stated in its Constitution, is "to further the public welfare wherever technical and engineering knowledge and experience are involved, and to consider and act upon matters of common concern to the engineering and allied technical professions."

The Council includes in its membership about 20 national, state, and local engineering societies. Under the plan of reorganization recently adopted for the purpose of making further reductions in the operating expenses of the Council, the assembly and the administrative board were combined, and the number of representatives reduced. The A.S.C.E., A.S.M.E., and the Institute now have 5 representatives each, 2 other societies have 1 each, and there are 6 regional representatives for state and local societies. In addition, past-presidents serve for 6 years after the expiration of their terms as president without being accredited to any member organization. L. W. Wallace, who had served as executive secretary since the organization of the Council, resigned in January 1934, and was succeeded by F. M. Feiker.

The wide variety of types of activities in which the Council engages is illustrated by the titles of the special committees which have been continued for 1934, as follows: administration of public works; air transport service in foreign commerce; communications; competition of governmental agencies with engineers in private practice; engineers water power policy; flood control; naval towing tank; patents; relation of consumption, production, and distribution; state engineering councils; telephone directory classification of engineers; water resources; and committee to appear before coordination committee of founder societies.

The many important developments in progress or contemplated which will have strong influences upon the engineering profession and upon the public welfare in matters directly involving engineering have placed heavy demands for assistance upon the Council during the past year. It is endeavoring to serve as effectively as possible the engineering profession and through it the public welfare.

United Engineering Trustees, Inc.

This organization, formerly United Engineering Society, was set up by the 4 national societies of civil, mining, mechanical, and electrical engineers to hold in trust and to administer for them the Engineering Societies Building, in which their headquarters are located, certain funds, and the library. Its charter gives it broad powers for the advancement of the engineering arts and sciences.

Extracts from the annual report of the United Engineering Trustees, Inc., were published on p. 633 of the April 1934 issue of Electrical Engineering.

Engineering Foundation

This department of United Engineering Trustees, Inc., was established in 1914 by the national societies of civil, mining, mechanical, and electrical engineers "for the furtherance of research in science and in engineering, or for the advancement in any other manner of the profession of engineering and the good of mankind." It was conceived by Ambrose Swasey, of Cleveland, Ohio, and he has made 4 gifts toward its endowment. The fund has been generously increased through the gifts of the late Edward D. Adams and others, and also through a bequest of the late Henry R. Towne.

Appropriations have been made for various research projects, and coöperation has been extended in others.

During the past few years the Foundation has supplied substantial financial assistance for 2 researches sponsored by the A.I.E.E. committee on electric welding, one at the Massachusetts Institute of Technology and the other at Lehigh University. The former was completed, and the latter is to be continued during 1934.

Engineering Societies Library

The library is administered as a free public library under the direction of the library board of United Engineering Trustees, Inc., this board being composed of representatives of the national societies of civil, mining, mechanical, and electrical engineers.

The library contains about 132,712 books and pamphlets. It receives regularly about 1,200 technical periodicals in many languages, and many additional publications issued irregularly.

A staff of technically trained searchers and translators is maintained. The staff is prepared to furnish the following types of service: photoprints, abstracts, translations, bibliographies, searches, etc. Special arrangements have been made for lending books.

Engineers' Council for Professional Development

A conference on certification composed of representatives of the national societies of chemical, civil, electrical, mechanical, and mining engineers, the Society for the Promotion of Engineering Education, and the National Council of State Boards of Engineering Examiners approved, in 1932, a plan for joint action of these organizations for the enhancement of the professional status of the engineer, and recommended the formation of the Engineers' Council for Professional Development. The participating bodies ratified the plan, and the organization of E.C.P.D. was effected in the fall of 1932. The council consists of 21 members, 3 representing each of the participating bodies.

The first annual meeting of E.C.P.D. was held October 10, 1933, and certain recommendations and matters of policy were approved. The principal recommendations deal with accrediting of engineering schools, minimum definition of an engineer, and suggested greater uniformity of grades of membership among the professional societies. These matters are now under consideration by the participating bodies.

Representatives

The Institute has continued its representation upon various national committees and other local and national bodies with which it has been affiliated in past years. A complete list of representatives was published in the September issue of Electrical Engineering, and in the 1934 Year Book.

Finance Committee

During the year the committee has held meetings frequently, has passed upon the expenditures of the Institute for various purposes, and otherwise performed the duties prescribed for it in the constitution and by-laws.

Haskins and Sells, certified public accountants, have audited the books, and their report follows.

Respectfully submitted for the board of directors,

H. H. Henline,

National Secretary

May 25, 1934

HASKINS & SELLS
CERTIFIED PUBLIC ACCOUNTANTS

22 EAST 40TH STREET
NEW YORK

May 18, 1934

American Institute
of Electrical Engineers,
33 West 39th Street,
New York.

Dear Sirs:

We have made an examination of your accounts for the purpose of verifying the stated financial condition at April 30, 1934, and have made an examination of your records of cash receipts and disbursements for the year ended that date. We submit the following exhibits and schedule:

Exhibit

A—Balance Sheet, April 30, 1934.
Schedule 1—Property Fund and Restricted Funds—Securities, Cash, and Accrued Interest Receivable.

B—Statement of Cash Receipts and Disbursements of General Fund for the Year Ended April 30, 1934.

C—Statement of Cash Receipts and Disbursements of Property Fund and Restricted Funds for the Year Ended April 30, 1934.

In our opinion Exhibit A sets forth your financial condition at April 30, 1934, and Exhibits B and C set forth your receipts as recorded and your disbursements during the year ended that date.

Yours truly,

Haskins & Sells

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Balance Sheet, April 30, 1934

Exhibit A

ASSETS			LIABILITIES		
Property Fund Investments:			Property Fund Reserve		$558,768.11
One-fourth interest in real estate and other assets of United Engineering Trustees, Inc., exclusive of Trust Funds	$496,948.48		**Restricted Fund Reserves:**		
Equipment:			Reserve Capital Fund	$154,528.25	
Library—Volumes and fixtures	37,296.37		Life Membership Fund	10,290.37	
Office furniture and fixtures (less reserve for depreciation, $21,124.09)	11,456.91		International Electrical Congress of St. Louis Library Fund	4,711.29	
Works of art, etc.	3,001.35		Lamme Medal Fund	4,685.78	
Securities and cash—Schedule 1	10,065.00		Mailloux Fund	1,035.18	
Total property fund investments		$558,768.11	Total restricted fund reserves		175,250.87
Restricted Fund Investments—Schedule 1:			**Current Liabilities:**		
Securities—At cost (less reserve for bonds of doubtful value)	$167,179.02		Accounts payable	$ 9,450.66	
Cash	7,848.52		Dues received in advance	2,684.45	
Accrued interest receivable	223.33		Entrance fees and dues advanced by applicants for membership	480.50	
			Subscriptions for "Quarterly Transactions" received in advance	88.00	
			Miscellaneous	66.65	
Total restricted fund investments		175,250.87	Total current liabilities		12,770.26
Current and Working Assets:			Surplus		62,349.60
Cash	$ 29,824.74				
Accounts receivable:					
Members—For dues	28,082.79				
Advertisers	60.00				
Miscellaneous	3,687.27				
Accrued interest on investments	2,243.59				
Inventories:					
"Quarterly Transactions"	4,714.25				
Text and cover paper	5,888.93				
Badges	618.29				
Total current and working assets		75,119.86			
Total		$809,138.84	Total		$809,138.84

Notation: In accordance with the usual practice of the Society, no provision has been made for dues which may prove to be uncollectable.

Property and Restricted Funds—Securities, Cash, and Accrued Interest Receivable, April 30, 1934

Exhibit A, Schedule 1

	Number of Shares of Stock or Face Value of Bonds	Property Fund (Equipment Replacements)	Restricted Funds: Reserve Capital Fund	Life Membership Fund	International Electrical Congress of St. Louis Library Fund	Lamme Medal Fund	Mailloux Fund	Total
SECURITIES								
Railroad Bonds:								
Baltimore & Ohio Railroad Company 6% refunding and general mortgage series C, due 1995	$12,000.00		$ 8,940.00			$4,330.00		$ 13,270.00
Central of Georgia Railway Company 5% consolidated mortgage, due 1945	3,000.00		1,477.50					1,477.50
Chicago, Burlington & Quincy Railroad Company 4%, due 1958	5,000.00			$ 4,868.75				4,868.75
Chicago, Burlington & Quincy Railroad Company 5% first and refunding mortgage series A, due 1971	1,000.00		1,010.00					1,010.00
Chicago & Erie Railroad Company 5% first mortgage, due 1982	1,000.00		1,105.00					1,105.00
Chicago & Northwestern Railway Company 6½%, due 1936	9,000.00		7,202.50					7,202.50
Chicago, Terre Haute & Southeastern Railway Company 5% first and refunding mortgage, due 1960	8,000.00		7,940.00					7,940.00
Florida East Coast Railway Company 5% first and refunding mortgage series A, due 1974 (certificates of deposit)	10,000.00		9,818.75					9,818.75
New York Central Railroad Company 5% refunding and improvement mortgage series C, due 2013	6,000.00		5,742.50					5,742.50
Pennsylvania Railroad Company 4½% general mortgage series A, due 1965	5,000.00		5,130.00					5,130.00
St. Louis-San Francisco Railway Company 5% prior lien mortgage series B, due 1950 (certificate of deposit)	6,000.00		5,497.50					5,497.50
Southern Railway Company 5% first consolidated mortgage, due 1994	1,000.00		980.00					980.00
Western Pacific Railroad Company 5% series A, due 1946	15,000.00		7,225.00					7,225.00
Total railroad bonds—(Forward)			$ 62,068.75	$ 4,868.75		$4,330.00		$ 71,267.50

Property and Restricted Funds—Securities, Cash, and Accrued Interest Receivable, April 30, 1934

Exhibit A, Schedule 1

	Number of Shares of Stock or Face Value of Bonds	Property Fund (Equipment Replacements)	Restricted Funds: Reserve Capital Fund	Life Membership Fund	International Electrical Congress of St. Louis Library Fund	Lamme Medal Fund	Mailloux Fund	Total
SECURITIES—Continued								
Total Railroad Bonds—(Forward)			$ 62,068.75	$ 4,868.75		$4,330.00		$ 71,267.50
Public Utility Bonds:								
Consolidated Gas Company of New York 5½% debentures, due 1945	$ 5,000.00		$ 5,187.50					$ 5,187.50
Duquesne Light Company 4½% first mortgage series A, due 1967	3,000.00		2,970.00					2,970.00
Hydro-Electric Power Commission of Ontario 3½%, due 1952	4,500.00		4,500.00					4,500.00
New York Telephone Company 4½%, due 1939	2,000.00				$ 878.75		$1,000.00	1,878.75
Pacific Gas & Electric Company 5½% first and refunding mortgage series C, due 1952	5,000.00		5,137.50					5,137.50
Philadelphia Company secured 5% series A, due 1967	10,000.00		10,000.00					10,000.00
Shawinigan Water & Power Company 4½% first mortgage and collateral trust sinking fund series A, due 1967	5,000.00		4,581.25					4,581.25
Texas Electric Service Company 5% first mortgage, due 1960	4,000.00		3,910.00					3,910.00
United Light & Power Company 5½% first lien and consolidated mortgage, due 1959	5,000.00		4,975.00					4,975.00
Total public utility bonds			$ 41,261.25		$ 878.75		$1,000.00	$ 43,140.00
Industrial Bonds:								
American Smelting & Refining Company 5% first mortgage series A, due 1947	$ 9,000.00		$ 9,085.00					$ 9,085.00
Bethlehem Steel Company 5% purchase money and improvement mortgage sinking fund, due 1936	5,000.00		5,033.75					5,033.75
Cleveland Union Terminals Company 5% sinking fund series B, due 1973	4,000.00	$4,010.00						4,010.00
Fidelity Union Title and Mortgage Guaranty Company first mortgage certificates (on property 75–79 Prospect Street, East Orange, N. J.) 5½%, due 1933	$14,663.00	977.53	13,685.47					14,663.00
International Match Corporation 5% convertible debentures, due 1941 (certificate of deposit)	3,000.00		2,880.00					2,880.00
New York Steam Corporation 6% first mortgage, due 1947	10,000.00		10,837.50					10,837.50
United States Rubber Company 5% first and refunding mortgage series A, due 1947	2,000.00		1,915.00					1,915.00
Western Electric Company 5% debentures, due 1944	10,000.00		9,818.75					9,818.75
Youngstown Sheet and Tube Company 5% first mortgage sinking fund series A, due 1978	10,000.00		10,137.50					10,137.50
Total industrial bonds		$4,987.53	$ 63,392.97					$68,380.50
Municipal Bonds:								
New York City 4½% corporate stock, due 1957	2,000.00				$2,204.05			$ 2,204.05
Capital Stocks:								
Commonwealth Edison Company	12 shares		$ 2,892.00					$ 2,892.00
Consolidated Gas Company of New York, $5.00 cumulative preferred	30 "	$ 3,060.00						3,060.00
Public Service Corporation of New Jersey, $5.00 preferred	30 "		2,958.75					2,958.75
United Gas Improvement Company, $5.00 preferred	30 "	1,995.00	997.50					2,992.50
Total capital stocks		$ 5,055.00	$ 6,848.25					$ 11,903.25
Total securities		$10,042.53	$173,571.22	$ 4,868.75	$3,082.80	$4,330.00	$1,000.00	$196,895.30
Less Reserve for Bonds of Doubtful Value:								
Central of Georgia Railway Company 5% consolidated mortgage, due 1945	$ 3,000.00		$ 1,477.50					$ 1,477.50
Florida East Coast Railway Company 5% first and refunding mortgage series A, due 1974	10,000.00		9,818.75					9,818.75
International Match Corporation 5% convertible debentures, due 1941	3,000.00		2,880.00					2,880.00
St. Louis-San Francisco Railway Company 5% prior lien mortgage series B, due 1950	6,000.00		5,497.50					5,497.50
Total reserve for bonds of doubtful value			$ 19,673.75					$ 19,673.75
Total Securities, Less Reserve		$10,042.53	$153,897.47	$ 4,868.75	$3,082.80	$4,330.00	$1,000.00	$177,221.55
Cash		22.47	630.78	5,388.29	1,560.99	255.78	12.68	$ 7,870.99
Accrued Interest Receivable				33.33	67.50	100.00	22.50	223.33
Total property fund securities and cash		$10,065.00						$ 10,065.00
Total restricted fund investments			$154,528.25	$10,290.37	$4,711.29	$4,685.78	$1,035.18	$175,250.87

Statement of Cash Receipts and Disbursements of General Fund for the Year Ended April 30, 1934

Exhibit B

Cash on Deposit, May 1, 1933, With the National City Bank of New York		$ 15,648.46
Receipts:		
Dues (including dues allocated to members "Electrical Engineering" subscriptions)	$162,285.88	
Advertising	17,036.74	
"Electrical Engineering" non-member subscriptions	10,375.18	
"Quarterly Transactions" subscriptions	9,436.64	
Miscellaneous publications, etc.	3,321.32	
Students dues	8,109.50	
Entrance fees	3,460.00	
Badges	1,188.50	
Transfer fees	834.46	
Interest on investments and bank balances	8,567.92	
Miscellaneous	35.56	
Total receipts		224,651.70
Total		$240,300.16
Disbursements:		
Publication expenses:		
"Electrical Engineering"	$ 65,248.35	
"Quarterly Transactions"	10,895.37	
Technical papers	3,792.22	
Year book	5,965.10	
Miscellaneous	1,024.40	
Administrative expenses	41,280.10	
Institute Sections	23,572.10	
Institute meetings	8,814.30	
Institute Branches	2,082.04	
American Engineering Council	9,250.00	
Forward	$171,923.98	$240,300.16

Total—(Forward)		$240,300.16
Disbursements—(Forward)	$171,923.98	
Traveling expenses:		
Board of Directors	2,565.69	
Branch Counselors	1,444.19	
Geographical districts:		
Executive Committees	1,117.75	
Vice-Presidents	440.88	
National Nominating Committee	1,207.90	
President's Special Appropriation	1,012.25	
United Engineering Trustees, Inc.:		
Library assessment	7,926.02	
Building assessment	2,966.40	
Standards Committee	4,406.87	
Membership Committee	5,188.29	
Employment service	3,535.44	
American Standards Association	1,333.33	
Badges	948.96	
Loss on exchange	500.85	
Retirement salary	2,700.00	
Finance Committee	400.00	
United States National Committee of International Commission on Illumination	300.00	
Geographical District prize—Best Branch paper	135.00	
Technical Committees	200.31	
Headquarters Committee	17.00	
Code Committee	60.00	
Edison Medal Committee	144.31	
Total disbursements		210,475.42
Cash on Deposit, April 30, 1934, With the National City Bank of New York		$ 29,824.74

Statement of Cash Receipts and Disbursements of Property Fund and Restricted Funds for the Year Ended April 30, 1934

Exhibit C

			Restricted Funds				
	Total	Property Fund (Equipment Replacements)	Reserve Capital Fund	Life Membership Fund	International Electrical Congress of St. Louis Library Fund	Lamme Medal Fund	Mailloux Fund
Cash on Deposit May 1, 1933, With East River Savings Bank and National City Bank of New York	$8,036.80		$316.25	$6,019.50	$1,459.59	$235.78	$ 5.68
Receipts:							
Principal of mortgage certificates—Partial collection	$ 337.00	$22.47	$314.53				
Interest on bonds	620.00			$ 200.00	$ 135.00	$240.00	$45.00
Interest on bank balances	166.15			166.15			
Total receipts	$1,123.15	$22.47	$314.53	$ 366.15	$ 135.00	$240.00	$45.00
Total	$9,159.95	$22.47	$630.78	$6,385.65	$1,594.59	$475.78	$50.68
Disbursements:							
Annual withdrawal authorized in by-laws	$ 997.36			$ 997.36			
Bronze and gold replicas of Lamme Medal	220.00					$220.00	
Other disbursements	71.60				$ 33.60		$38.00
Total disbursements	$1,288.96			$ 997.36	$ 33.60	$220.00	$38.00
Cash on Deposit, April 30, 1934, With East River Savings Bank and National City Bank of New York	$7,870.99	$22.47	$630.78	$5,388.29	$1,560.99	$255.78	$12.68

The Expulsion Oil Circuit Breaker

In the expulsion type of oil circuit breaker the arc occurring on circuit interruption is "expelled" from the contact chamber by a high velocity gas blast. Breakers of this type have demonstrated their capability of consistently interrupting short circuits on a typical large electric power system within 1 or 2 cycles of arc. In this paper the theory of this type of breaker is presented and its performance is analyzed.

By
A. C. SCHWAGER
MEMBER A.I.E.E.

Pacific Elec. Mfg. Co.
San Francisco, Calif.

THE CONTINUALLY growing capacity of high voltage electric power systems and the resultant demand for fast circuit interruption has brought about in the last few years the development of greatly improved circuit interrupters. The duration of the short-circuit time has been shortened by eliminating part of the mechanical time lag of the opening motion and by reducing the arcing time. The plain circuit breaker has been substituted by devices bringing about a more rapid and smooth interruption of the arc. This paper is limited to the electrical problem of arc interruption.

Interruption in a circuit breaker with not more than $^1/_2$ cycle of arc is obviously the ultimate goal to be accomplished. This requirement has been met for moderate voltages by several new devices; for higher voltages the arcing time is consistently longer and often still excessive. The reduction in arcing time brings about a reduction in arc energy sometimes to 5 per cent of the value obtained under identical conditions with a plain oil circuit breaker. It is well known, however, that a vacuum switch can interrupt currents with an arc energy of extremely small magnitude when compared with the best oil circuit breakers. The question, therefore, arises as to whether it is possible to build an arc rupturing device for an oil circuit breaker that approaches the performance of the vacuum breaker and what minimum value of arc energy would be required for interruption. In this paper such a design is shown to be feasible. A high-voltage high-capacity expulsion type oil circuit breaker has demonstrated its capability of consistently interrupting short circuits on a typical large electric power system under various conditions over a range from 1 to 100 per cent of maximum rated short-circuit current with from 1 to 2 cycles of arc. Arc energy and gas generation have been reduced to values heretofore not reached, with oil deterioration and carbonization practically eliminated. Interruption up to full rated capacity occurs with no other external sign than that resulting from the motion of the operating mechanism.

Full text of a paper recommended for publication by the A.I.E.E. committee on protective devices, and scheduled for discussion at the A.I.E.E. Pacific Coast convention, Salt Lake City Utah, Sept. 3–7, 1934. Manuscript submitted May 9, 1934; released for publication June 8, 1934. *Not published in pamphlet form.*

Theory of the Expulsion Circuit Breaker

For many years, it has been realized that an arc is deionized more effectively in an atmosphere of hydrogen than in any other gas. This accounts for the short arc lengths obtained in the conventional plain-break oil circuit breaker, which burns essentially in a hydrogen atmosphere, when compared with the large distances to which an arc has to be drawn in air to effect interruption. Recent investigations show that an arc in hydrogen burns at much smaller *diameter* than an arc in air, for identical currents (Kesselring, *Elektrotechnische Zeitschrift*, v. 55, p. 92). The diameter of the arc is one of the primary factors influencing the speed of deionization in the vicinity of the current zero period: the smaller the arc diameter, the more rapid the deionization. An arc in air can be forced to burn at a smaller diameter by subjecting it to a high velocity air blast, a fact that has been made use of for several decades in air blast devices. The smallest diameter and the most effective deionization of an arc for a certain current finally can be obtained by a combination of the foregoing 2 conditions, that is, by subjecting it to a blast of hydrogen gas. No detailed account will be given here of the factors responsible for this performance, such as diffusion, recombination, and specific heat; for a more detailed analysis the reader is referred to the excellent paper by Slepian on "The Extinction of Long A.C. Arcs" (A.I.E.E. Trans., v. 49, 1930, p. 421–30).

An arc under oil produces hydrogen by decomposition and it is not difficult to provide a device for forcing the hydrogen at high velocity through the arc. The conventional explosion chamber is but one example; however, its performance is not satisfactory with regard to arcing time, arc energy, and capacity to interrupt small currents. An ideal gas blast device should fulfill the following specifications:

1. Interruption should take place at the first current zero.
2. It should be equally effective for large and small currents (including charging currents of long transmission lines).
3. The amount of gas generated should be limited to the minimum necessary for definite interruption.

In the following paragraphs is described a gas blast device that should meet the foregoing specifications. Figure 1a illustrates the conventional explosion pot in the process of interruption with the movable contact in a position at which the first current zero occurs. The arc is burning in a stationary atmosphere of hot gases, gas blast action is entirely absent and reignition occurs. Only after the blade has left the throat is there a localized gas blast through it

which produces sufficient deionization to prevent reignition. On high voltages, interruption by means of such an explosion chamber requires 4 cycles of arc or more. As shown in Fig. 1b, the free escape of the deionizing gas stream is impeded seriously by the large volume of oil in the chamber. The high pressure gas bubble within the chamber forces a definite quantity of oil through the throat and causes the cross section of the gas blast to be small and erratic for the various duties under which it must operate. Figure 1c shows another well-known arrangement of an explosion pot, a hole being provided back of the fixed contact through which the gases can escape into the surrounding oil. Provided the gas pressure is high and the mass of the oil piston formed by the oil volume within the opening is sufficiently small, a gas blast is initiated in a very short time, causing interruption at an early current zero. This chamber has the additional advantage that, should the arc last until the movable contact has left the throat, it would become doubly effective because 2 oppositely directed gas blasts would be established as shown in Fig. 1d. However, the large amount of oil contained in such a chamber interferes with the free escape of the gas blast and makes the performance highly unsatisfactory.

To improve the operation of this contact it is necessary above all to establish a gas blast unimpeded by oil. This can be accomplished by a radical reduction in oil volume such as is shown in the construction represented in Fig. 2. The movable contact is withdrawn in a close fitting tube. Upon formation of the arc, the oil piston within the fixed contact is expelled and a free gas blast is established. The total oil volume of such a chamber easily can be limited to a few cubic inches, an amount greatly in excess of that decomposed and vaporized during the interruption. This contact in its appearance, as well as in its action of first expelling a piston of oil followed by a gas stream, has more similarity to the well-known expulsion fuse than to an explosion chamber and for this reason it is called an "expulsion contact"; a circuit breaker equipped with this contact is called an "expulsion circuit breaker."

The expulsion contact schematically represented in Fig. 2 has certain undesirable features, inherent also to the contact shown in Fig. 1c. All contact fingers are of the same length and burning can take place on any of them; in addition, upon establishing a gas blast the arc is deflected into the contact and made to burn on parts that in the closed position of the breaker act as current carrying surfaces, thereby reducing their carrying capacity and causing undue heating. The cross section of the expulsion chamber opening is fixed by the dimensions of the movable blade and therefore is not readily variable to a value that might prove more suitable for most efficient operation. A design such as that shown in Fig. 3 eliminates these disadvantages. An arcing tip projecting beyond the length of the main contacts is provided and an insulating tube the cross section of which can be selected independently of the cross section of the moving blade is located adjacent to this arcing tip. The oil volume is reduced to a small value by means of a filler as indicated in Section *AA*. This contact can be simplified in its construction by eliminating the tube, a cylindrical opening being formed by the wall of the chamber and the oppositely located spring of the arcing tip, as shown in Fig. 4. If a copper plate extending from the arcing tip to the outside of the chamber be provided to cover the spring, an additional highly desirable feature is obtained. The arc root establishing on the arcing tip, under the influence of the high velocity gas stream will be moved outward along the copper plate,

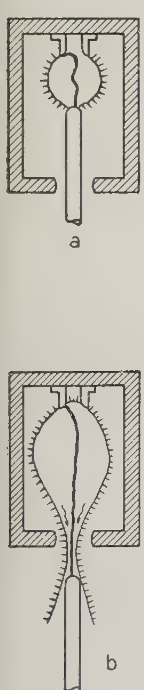


Fig. 1 (a and b). Conventional explosion pot during interruption

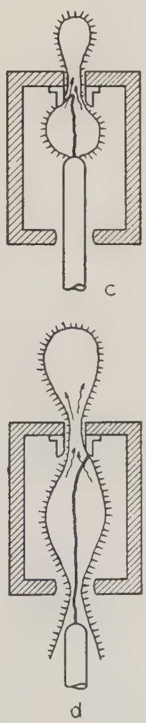


Fig. 1 (c and d). Explosion pot with end opening during interruption

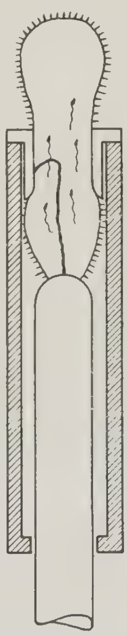


Fig. 2. Expulsion chamber in operation

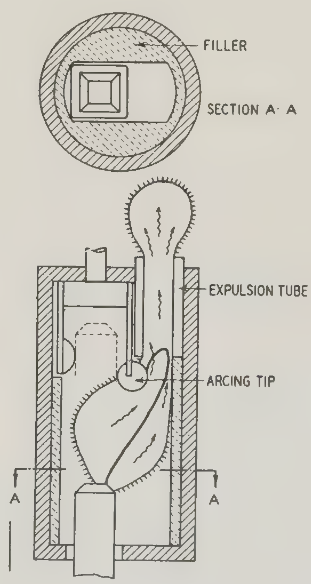


Fig. 3. Expulsion chamber with tubular blow-out opening

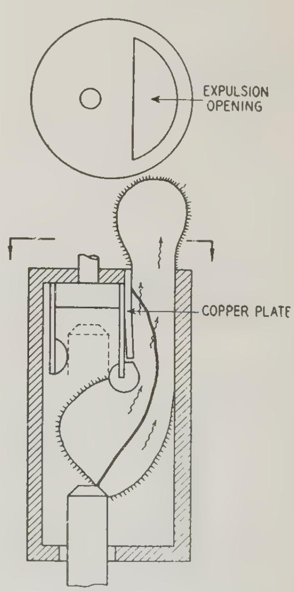


Fig. 4. Expulsion chamber with blow-out opening formed by arcing contact and main chamber tube

drawing the arc to a length several times the distance of contact separation and thereby greatly increasing the rate of deionization.

Performance of the Expulsion Contact

In the following paragraphs the performance of the expulsion contact shown in Fig. 4 under circuit interruption will be analyzed. Immediately upon contact separation an arc is formed between the arcing tip and moving blade, decomposing and vaporizing the surrounding oil and forming a high pressure gas bubble inside the chamber. Since the opening through the tube presents the only avenue of relief, the oil in the tube is accelerated and after a short period completely removed, whereupon a high velocity gas blast is established; this acts as a deionizing agent on the arc path, thereby preventing reignition at the next current zero. Therefore, *interruption or failure to interrupt should be related to the existence or absence, respectively, of a gas blast at current zero.*

The time to produce a gas blast is affected by various factors, principally by the quantity of gas generated and by the volume of oil to be removed from the expulsion tube. If the rate of gas generation be known it is possible to calculate the motion of the oil in the tube (hereafter called the oil piston) and to determine the time required for complete removal. Before proceeding with these calculations the most favorable time for removal will be discussed. As stated before, interruption is desired in $^1/_2$ cycle; therefore, if the oil piston is of such dimensions that it is not removed completely in that time, performance is unsatisfactory. If, however, the oil piston be removed in about $^1/_{10}$ cycle, the gas blast

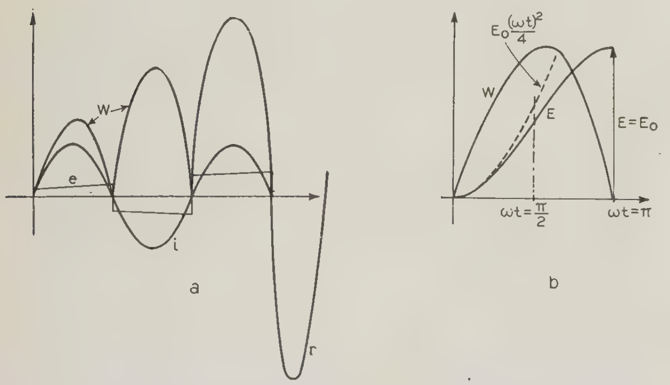
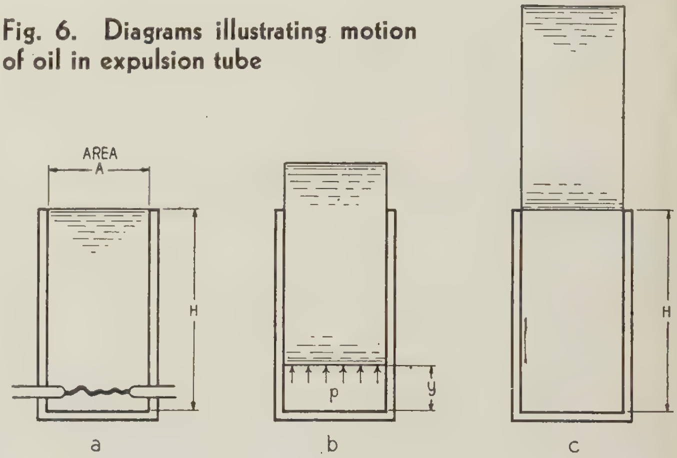


Fig. 5. Arc current, voltage, watts, and energy for an interruption taking place in 3 half cycles

is initiated at a time when interruption is neither possible nor desirable. In addition, a large quantity of gases escape in a period during which they could be accumulated for release immediately before current zero to produce a more effective action. The ideal performance requires the accumulation of the gases as nearly as possible at the first current zero in order that the formation of a fully effective gas blast may be accomplished at that instant. If the contacts separate at a current zero, the time for accumulation of gases is close to $^1/_2$ cycle; however, if separation take place at a current maximum, the gas blast should be established within $^1/_4$ cycle. To take care of these various conditions it seems advisable to set up the following requirement: Gas generation and dimensions of the oil piston shall be correlated in such a manner that a gas blast is established in $^1/_4$ cycle.

In the following calculations various assumptions have been necessary in order to obtain a solution; accordingly, the results should be taken qualitatively rather than quantitatively. For each assumption, an attempt has been made to choose conditions that would bring about a more rapid production of a gas blast, in order that the final result might formulate the conditions for the production of a gas blast

Fig. 6. Diagrams illustrating motion of oil in expulsion tube



in $^1/_4$ cycle. The gas blast is therefore more likely to exist previous to $^1/_4$ cycle and is very unlikely to start later than $^1/_4$ cycle after separation of the contacts.

Arc Energy

The amount of gas generated during the interruption of a short circuit is related directly to the amount of arc energy liberated. Figure 5a shows schematically an oscillogram of an interruption taking place in 3 half cycles; i represents the current, e the arc voltage, and r the first half cycle of recovery voltage. A curve showing instantaneous arc watts was computed as the product of current times arc voltage and is labeled W. Over each half cycle of arc this curve approximates a sine curve with its maxima displaced to the right of the maxima of the current wave and increasing rapidly with each successive half cycle. Considering only the first half cycle as shown in Fig. 5b and assuming a constant arc voltage e, the arc watts vary purely sinusoidally and are given by $W = eI_{max} \sin (\omega t)$, where $\omega = 2\pi f$. The arc energy up to the time t then follows:

$$E_t = \frac{eI_{max}}{\omega}(1 - \cos \omega t) \qquad (1)$$

and is plotted in Fig. 5a, curve E. Denoting by $E_0 = \frac{2eI_{max}}{\omega}$ the arc energy during $^1/_2$ cycle, the

Table I—12-Kv Tests on Expulsion Contacts

Contact No.	Dimensions of Expulsion Opening A, Sq Cm	H, Cm	Current Interrupted, Amp	Line Voltage, Kv	Kva Interrupted	Arc Times, Cycles	Total Gas Volume Cold, Cu Cm	$\frac{V_0}{4}$ Cu Cm	$\frac{V_0}{AH^3}$	P (Kg per Sq Cm) During First Half Cycle	Arc Energy During First Half Cycle Kw-sec	Total Arc Energy Kw-sec
1	5	13	3,530	12.1	42,500	1	1,300	350	0.13	15	4.2	16
2	1	2	3,600	12.3	44,000	0.25	350	350	173	13	4.2	4.2

energy E_t can be represented also by $E_t = \frac{E_0}{2}(1 - \cos \omega t)$ giving (see Fig. 5b) for small values of t

$$E_t \cong E_0 \frac{(\omega t)^2}{4} \quad . \quad 0 < \omega t \leqq \frac{\pi}{2} \tag{2}$$

Gas Generation

For a long time it has been established that a direct proportion exists between the arc energy and the amount of gas generated, one kilowatt-second of arc energy producing in the neighborhood of 50 cu cm of gas, measured at atmospheric pressure and temperature (see "Hochspannungsforschung und Hochspannungspraxis," by O. Mayr, Springer, 1931). Since the average temperature of the decomposed gases during interruption is not less than 500 deg C, their volume at atmospheric pressure practically is doubled. In addition, a considerable amount of oil is vaporized but not decomposed; when this is taken into consideration, the minimum total volume of hot gases produced per kilowatt-second is about 200 cu cm. Substituting this value into eq 2 gives the following for the volume of hot gases reduced to atmospheric pressure generated up to the time t:

$$V_t = 0.05E_0(\omega t)^2 \quad \text{in which } 0 < \omega t < \frac{\pi}{2}$$

Denoting with $V_0 = 0.2E_0$ the volume of gases generated in one-half cycle,

$$V_t \cong V_0 \frac{(\omega t)^2}{4} \qquad 0 < \omega t < \frac{\pi}{2} \tag{3}$$

Since, in general, the expansion of the gas bubble under oil is accompanied with changes in its pressure, information as to the mode of expansion, that is, whether isothermal or adiabatic is necessary. Because of the continuous liberation of energy by the arc, isothermal expansion is most probable and is confirmed by tests. Up to the point where a gas blast starts Boyle's law can be applied.

Motion of Oil Piston

Knowing the rate of gas generation it will be possible to determine the motion of the oil piston in the expulsion tube. In Fig. 6a such a tube is shown separately, consisting of a cylindrical vessel of cross section A and height H, closed at the bottom and open at the top. If gases are generated by an arc in the vicinity of the bottom, the entire oil piston will be accelerated. For simplicity of calculation, the entire oil piston shall be assumed to be solid and its removal shall take place according to Figs. 6b and 6c; the external pressure as well as the work done in lifting the piston shall be neglected.

Denoting the travel of the piston by y, its velocity by v, the pressure of the gas by p, the specific gravity by σ, and the acceleration due to gravity by g, it follows:

$$A \cdot H \cdot \frac{\sigma}{g} \cdot \frac{d^2y}{dt^2} = Ap \tag{4}$$

$$\frac{V_t}{p} = A \cdot y \tag{5}$$

Substituting eq 3 into eq 5, solving the differential equation, and assuming $\sigma = 0.0009$ kg per cubic centimeter and $f = 60$ cycles

$$y = 1.4 \times 10^5 \sqrt{\frac{V_0}{A \cdot H}}\, t^2 \quad \text{cm} \tag{6}$$

$$v = 2.8 \times 10^5 \sqrt{\frac{V_0}{A \cdot H}}\, t \quad \text{cm per second} \tag{7}$$

$$p = 0.25 \sqrt{\frac{H\, V_0}{A}} \text{ Kg per square centimeter} \tag{8}$$

giving the following condition for initiation of a gas blast within $1/4$ cycle:

$$\frac{V_0}{A \cdot H^3} \geqq 0.17 \tag{9}$$

all of the last 4 formulas applying for centimeters, kilograms, and seconds.

The motion of the oil piston is accelerated uniformly, y increasing with t^2, v with t, and p being constant—a fact that is particularly interesting since it justifies previous assumptions of an isothermal condition in the gas volume during the expulsion period. The quantities A and H are given by the particular design of expulsion contact and can be varied arbitrarily. However, V_0 is unknown, but is dependent directly on the arc energy liberated during the first half cycle. If V_0 were known it would be possible to select A and H according to eq 9 in order to produce interruption at the first current zero. Information covering a great many tests on oil circuit breakers shows that an arc energy of 0.5 kw-sec per 1,000 kva interrupted is as low a value as can be expected. In the following paragraphs an attempt shall be made to design an expulsion chamber capable of interrupting 40,000 kva (maximum capacity of testing station) at 12 kv in $1/2$ cycle. An interruption of 40,000 kva would liberate 20 kw-sec, producing a volume $V_0 = 4,000$ cu cm. Area A was made 5 sq cm and height H 13 cm, giving a value $\frac{V_0}{AH^3} = 0.36$ which is in excess of the required value of 0.17 necessary to produce interruption.

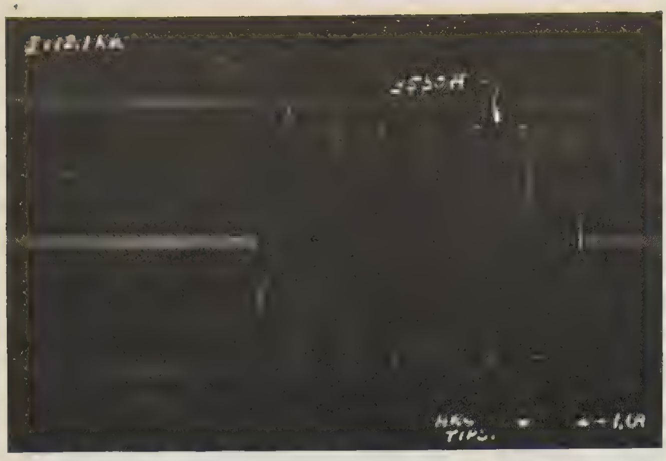


Fig. 7. Oscillogram showing the interruption of 3,530 amp at 12.1 kv with expulsion contact as shown in Fig. 4

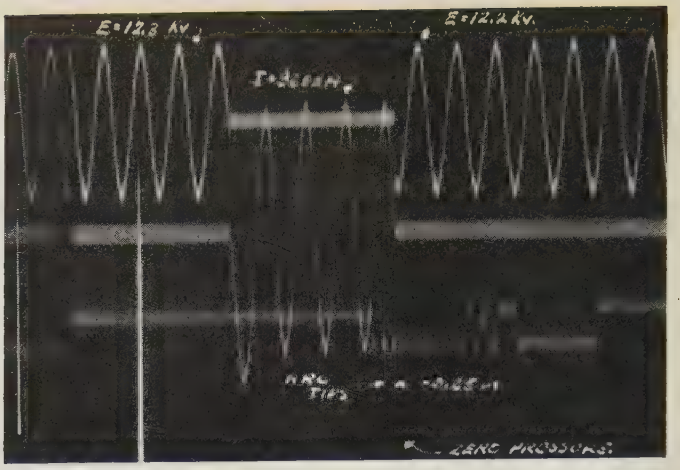


Fig. 7a. Oscillogram showing interruption of 3,600 amp at 12.2 kv with expulsion contact in 0.25 cycle

A single expulsion chamber according to Fig. 4, called contact No. 1, with dimensions of the expulsion piston as indicated in the preceding paragraph was built and tested. Figure 7 shows an oscillogram of an interruption which took place in 1 cycle instead of the expected $^1/_2$ cycle. The quantity of gas generated during the interruption was measured, allotted to each half cycle by means of the oscillographic record of the respective arc voltages, the values obtained being given in Table I.

The arc energy liberated during the first half cycle is considerably smaller than that anticipated, V_0 amounting to only 1,400 cu cm instead of 4,000 cu cm giving a ratio $\frac{V_0}{AH^3} = 0.13$, and therefore insufficient for interruption. To produce interruption at such a small value of V_0, AH^3 has to be reduced radically. A second contact (No. 2) was built and tested with $A = 1$ sq cm and $H = 2$ cm, the test results being shown in Fig. 7a and tabulated in Table I. Interruption took place in $^1/_4$ cycle with an arc voltage hardly visible on the oscillogram. The quantity of gas generated was not measured, but an estimate on the basis of arc voltages (Figs. 5 and 6) gives a value not exceeding 350 cu cm; therefore, $\frac{V_0}{AH^3}$ amounts to 173 for this contact, a value approximately 1,000 times larger than necessary. It is realized that an exceedingly small value of V_0 is capable of bringing about a gas blast in $^1/_2$ cycle; for contact No. 2 $V_0 = 1.4$ cu cm would appear sufficient. Whether or not such a small volume of gas is capable of interrupting the arc is not known. In an oil circuit breaker in which the arc can burn only if the voltage across it exceeds a definite minimum value, the volume of gas generated is in excess of 1.4 cu cm and apparently is sufficient to cause interruption upon establishment of the gas blast. It is hoped that further investigations can be carried out to determine the range of extremely low gas volumes where eq 9 represents only a necessary but insufficient condition for interruption at the first current zero.

The large value of $\frac{V_0}{AH^3}$, not necessarily required for the interruption of large currents, provides a feature that is most desirable in interrupting small currents, where arc energy and gas generation are small. Whereas most of the present circuit breakers show a highly increased arcing time for currents ranging from 2,000 amp to very small values, the expulsion contact can be expected to bring about interruption in substantially the same time over the entire current range; there should be no great difference in performance between an interruption of 10,000 amp and one of 100 amp. Table II substantiates this statement for contacts Nos. 1 and 2 for currents ranging from 3,600 down to 960 amp.

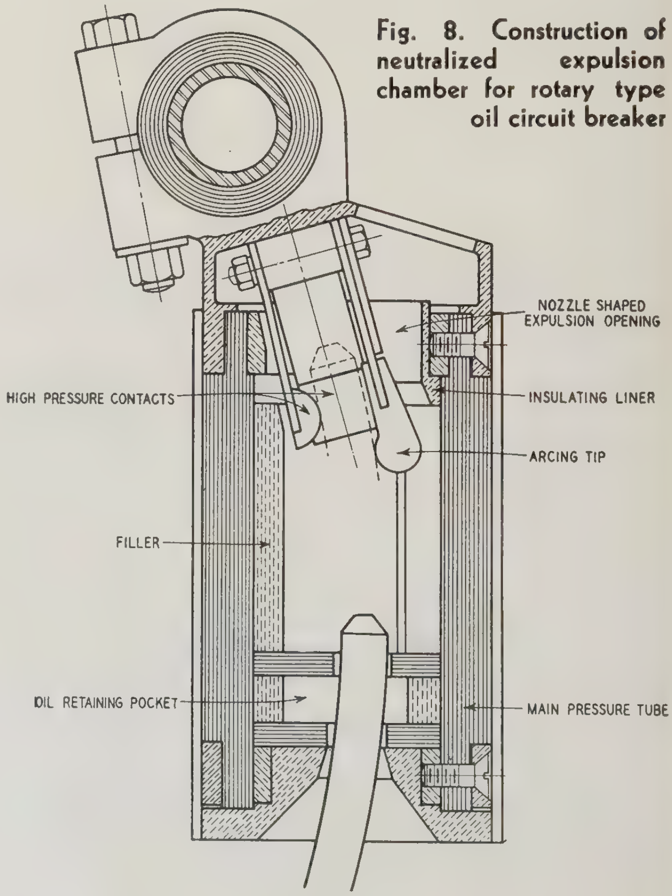


Fig. 8. Construction of neutralized expulsion chamber for rotary type oil circuit breaker

The tests from which the data of Table II were obtained have shown that it is possible to explain the interruption of an arc in an expulsion chamber on the presence of a gas blast. The theory developed allows the dimensions of the expulsion tube to be such that interruption is accomplished within $^1/_2$ cycle. An arc energy of 0.5 kw-sec per 1,000 kva, generally considered the best value attainable, by no means defines a circuit breaker of the best possible performance; values of 0.1 kw-sec and less are within easy reach with the expulsion chamber breaker.

Gas Blast

Having paid particular attention to the requirements for the removal of the oil piston from the expulsion tube and the subsequent initiation of a gas blast, the characteristics of the gas blast proper and in particular of its velocity of escape will be analyzed briefly. The gas blast escapes into a large body of oil surrounding the expulsion chamber, forming a rapidly expanding gas bubble. In general, the rate of escape of the gases due to accumulation over a part of the half cycle near the current zero will exceed the instantaneous rate of gas generation inside the chamber. It is well known that a gas stored at a pressure p_1 escapes through a cylindrical orifice with a velocity equal to the sound velocity of the gas under the prevailing condition of state, provided the external pressure p_2 does not exceed a value of approximately $^1/_2p_1$.

Because of gas bubbles forming outside the expulsion tube, the motion of the oil in the tank is similar in principle to the motion of the oil in the expulsion tube already analyzed. If the height of oil above the gas bubble is identified by H and its cross section by A, eqs 4 and 5, can be applied. It is estimated that with the large value of A prevailing in the conventional oil circuit breaker tank the pressure p_2 set up by an extremely high rate of gas generation will not reach a value of $^1/_2p_1$; the gases, therefore, escape at the velocity of sound, that is, at 660 m per second (2,300 ft per second) or more. Velocities exceeding sound velocity are obtained if the cylindrical opening be replaced by an outwardly flared nozzle; such a construction favors rapid deionization and carries the arc root farther along, and is incorporated in the final contact design.

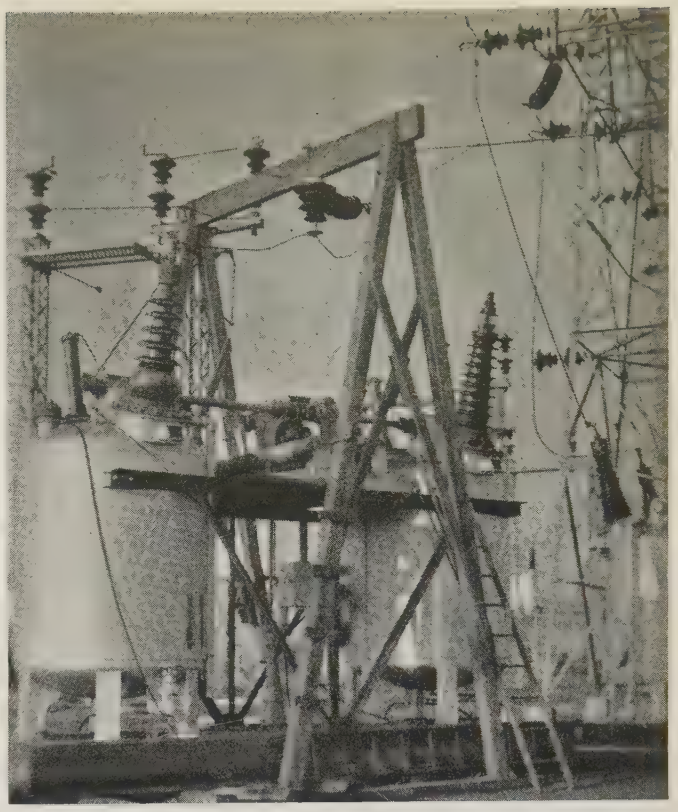


Fig. 10. Set-up for 110-kv field tests

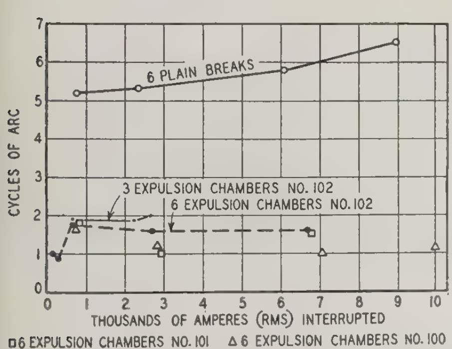


Fig. 9. Relation between current interrupted and arcing cycles for different types of contacts on 110-kv tests

Table II—Arcing Time of Expulsion Contacts for Small Currents

Contact No.	Amperes Interrupted at 12 Kv	Arcing Time, Cycles
1	960	1.2
	1,980	1.3
	3,530	1.0
2	980	0.4
	1,730	0.4
	3,600	0.25

Mechanical Forces During Interruption

A conventional explosion chamber, as shown in Fig. 1a, is known to exert large and sometimes harmful reactions upon the supporting entrance bushing. This is because the pressure produced by the accumulation of gases over several cycles acts upon different wall areas on the top and bottom of the chamber. A gas blast escaping into a body of oil also produces a reaction upon the chamber if active independently of any other force, although its value is small with an expulsion chamber because of the early relief and the subsequent moderate internal pressure. It is evident that the reaction upon an ordinary explosion chamber can be neutralized when it is combined with a gas blast of proper momentum and direction. It has been found that an expulsion chamber in which the throat area is approximately equal to that of the expulsion tube produces close equalization. For practical applications on circuit breakers of 600- and 1,200-amp capacity, a piston according to contact 1, Table I, has been found to give better results than one according to Contact 2. This contact, therefore, has been chosen for the

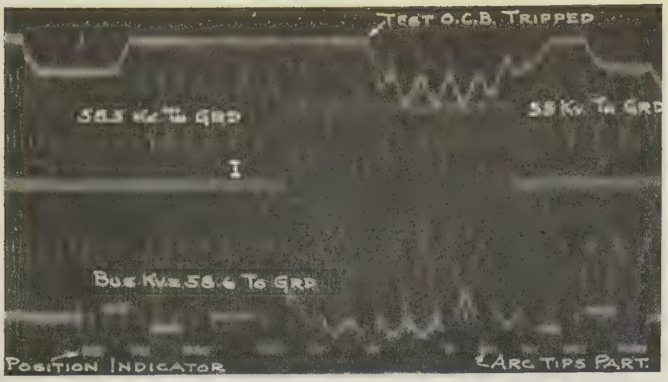


Fig. 11. Oscillogram showing interruption of 10,000 amp, single phase to ground, on 110-kv system with expulsion contacts No. 100

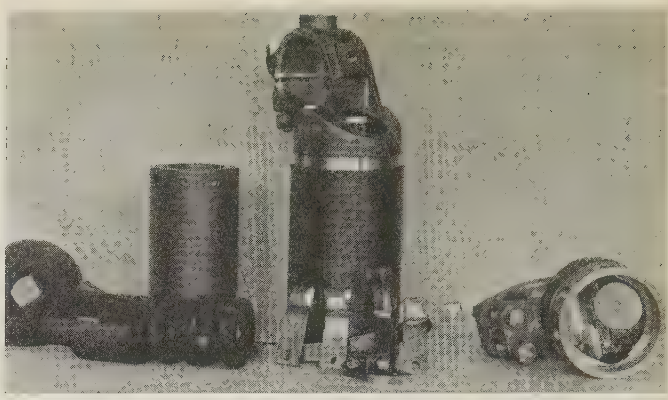


Fig. 12. Contact No. 102 after series of tests

following practical applications in spite of the fact that $^1/_2$ cycle of arcing time thereby is sacrificed.

Figure 8 shows the detailed construction of a neutralized expulsion chamber as it is used on a rotary type oil circuit breaker. Besides the neutralization of pressures, the following features are incorporated:

1. Main expulsion chamber of small volume, obtained by arc resisting fillers.
2. Nozzle shaped expulsion opening.
3. Arcing tip and adjacent copper plate provide means for elongating arc.
4. High pressure line contacts enable the blade to leave the arcing tip after a very short travel; no burning occurs on these contacts.
5. Oil retaining pocket providing reservoir for decomposing oil, should the arc be carried through throat.

Application of Expulsion Contacts to High Voltage Circuit Breakers

Because of the poor deionization of the arc path during the current zero period, the arc in a plain oil circuit breaker has to be drawn to considerable length to effect interruption; the arc in such a breaker is reestablished along the old insufficiently deionized path, although the surrounding gas is capable of withstanding the recovery voltage. In proceeding to the well deionized arc path of the expulsion contact, conditions are found to be different, a breakdown being more likely to occur through the gaseous atmosphere between the arcing tip and the movable contact. Restriking along the old arc path, which is drawn to a length many times the distance of contact separation and cooled over its entire length, is not probable.

Tests on contact No. 1 at 12 kv showed interruption of 3,600 amp in $^1/_4$ cycle with only $1^1/_4$-in. contact separation. If the same current were applied at 60 kv, deionization would be equally effective, but the breakdown distance of $1^1/_4$ in. would be insufficient to prevent reignition. The dielectric strength of the gas bubble has a definitely limited value, prevention of breakdown through it at 60 kv requiring a break distance of approximately 10 in. If this chamber were to interrupt currents at such a high voltage in $^1/_2$ cycle, a contact speed in excess of 50 ft per second would be required, a value which is not feasible because of the excessive mechanical forces required to bring about such velocities. Even the use of the conventional 2-break switch at half that velocity is impractical. The multiple break switch, however, has the advantage of introducing the insulating gas at a much higher rate for blade velocities in general use, and for electrical as well as mechanical reasons represents the ideal arrangement. It has the additional advantage that the total resulting break distance is so large that interruption can be obtained when operating with plain contacts, giving a factor of safety not common on 2-break switches.

Field Tests at 110 Kv

Plain-Break Oil Circuit Breaker. A 115-kv 6-break rotary type circuit breaker provided with plain contacts was submitted first to interrupting capacity tests. Since single-phase-to-ground short circuits constitute the most common faults and produce maximum short circuit currents, tests were made with this connection. At the Newark (Calif.) substation of the Pacific Gas and Electric Company's transmission system short circuits ranging from 700 to 9,000 amp were interrupted by a single phase of the

Table III—Results of 110-Kv Field Tests on a 6-Break Rotary Type Oil Circuit Breaker With Plain Contacts

Test No.	Duty Cycle	Amperes Interrupted	Recovery Kv	Cycles of Arc	Pressure in Tank, Lb per Sq In.	Oil Throw, Gal	Oil Dielectric Strength After Test	Interrupted Single-Phase Kva	Equivalent 3-Phase Kva
1	OCO	745	53	5.2		None	Above 27	39,500	120,000
2	OCO	2,350	59	5.3	7.5	None	Not tested	138,000	415,000
3	OCO	6,050	60	5.8	55	$1^1/_2$	Not tested	362,000	1,080,000
4	OCO	8,950	56	6.5	125	8	Above 27	501,000	1,500,000

Table IV—Results of 110-Kv Field Tests on an Oil Circuit Breaker Equipped With No. 102 Expulsion Contacts (See Fig. 8)

Test No.	No. of Breaks	Breaker Cycle	Breaker Duty	Current, Amp Initial	Current, Amp Interrupted	Recovery Kv	Interrupted Single Phase Kva	Equivalent 3-Phase Kva	Cycles of Arc	Total Cycles for Breaker to Clear	Tank Press, Lb per Sq In.	Gas Volume at 20° C and Atmospheric Pressure, Cu Cm
1	6	OCO	Short circuit		700	63	45,000	135,000	1.7	5.2	0	Less than 4,000
2	6	OCO	Short circuit	3,800	2,800	65	182,000	546,000	1.6	5.2	0	8,000
3	6	OCO	Short circuit	7,700	6,200	63	390,000	1,179,000	1.6	5.3	0	8,000
4	6	CO	Charging current		145	76	9,000	27,000	1.0	4.4	0	Less than 4,000
5	6	CO	Charging current		265	94.5	17,000	51,000	0.9	4.3	0	Less than 4,000
6	3	OCO	Short circuit		700	62	43,000	129,000	1.6	5.0	0	Less than 4,000
7	3	OCO	Short circuit	5,000	2,700	62.5	169,000	500,000	1.9	5.2	0	Less than 4,000
8	3	OCO	Short circuit	6,400	2,300	62	143,000	430,000	2.0	5.4	0	8,000

test breaker. The results are tabulated in Table III. The relation between arcing time and short-circuit current is shown in Fig. 9.

Expulsion Oil Circuit Breaker. A 115-kv breaker identical in size to the plain breaker tested first was equipped with 3 different types of expulsion contacts, varying in design features, but all being based upon the expulsion principle. For the purpose of identification they will be denoted as contacts Nos. 100, 101, and 102, respectively. Contact No. 100 is shown in Fig. 3, No. 101 in Fig. 1c, and No. 102 represents the final design shown in Fig. 8. Figure 10 shows the field set-up of the test breaker to which these contacts alternately were applied. Single-phase short circuits on the 110-kv system, ranging from 770 to 10,000 amp (rms interrupted current) applied to contacts Nos. 100 and 101 were cleared with less than 2 cycles of arcing time. In no case was a drop of oil thrown, and the dielectric strength of the oil remained unchanged. Figure 11 shows an oscillogram of an interruption of 10,000 amp by Contact No. 100 in 1.1 cycle; the arc voltage is hardly noticeable. Results of all individual tests on contacts Nos. 100 and 101 are plotted in Fig. 9. Since tank pressures on this test were too small to be recorded and no trace of gases escaping through the vent pipe was noticed, it was decided to measure the volume of gases generated during the tests of contact No. 102. The single-phase-to-ground current tests were supplemented by charging current tests. Table IV gives a summary of the test results.

One of the contacts after test is shown in Fig. 12. Except for a slight burning on the stationary and movable arcing contact tips there was no trace of the interruptions on any of the contacts. The oscillogram recorded during test No. 3 is shown in Fig. 13; the arc voltage is hardly noticeable. The charging current oscillogram shown in Fig. 14 is particularly interesting since it shows interruption taking place in one cycle. Additional tests 6, 7, and 8 on a breaker equipped with 3 contacts showed arcing times not in excess of 2 cycles and give an indication of the performance that can be obtained with 6 expulsion chambers on voltages of 220 kv and higher.

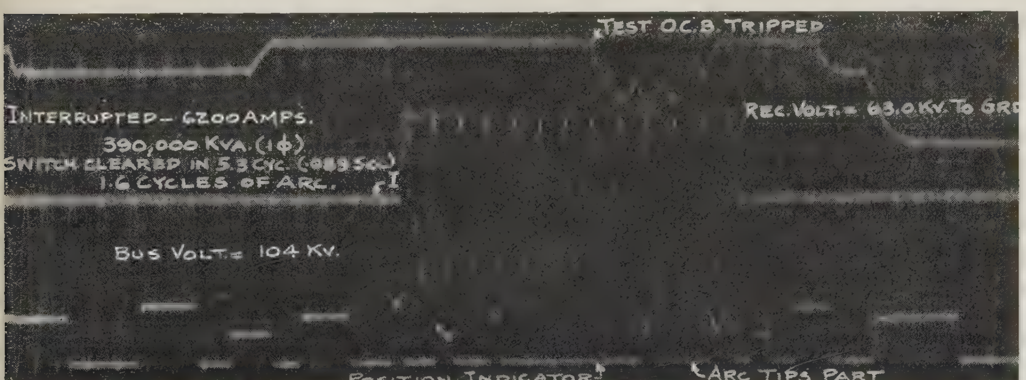


Fig. 13. Oscillogram showing interruption of 6,200 amp, single phase to ground, on 110-kv system with expulsion contacts No. 102

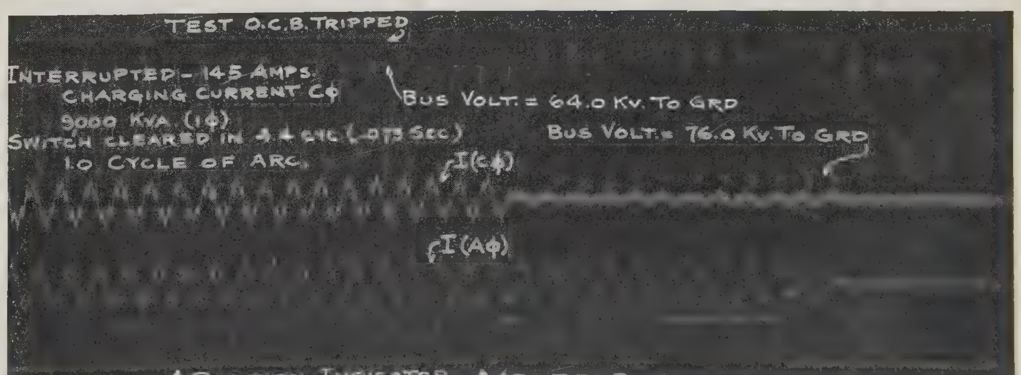


Fig. 14. Oscillogram showing interruption of charging current on 110-kv system with contacts No. 102

Counterpoise Tests at Trafford

Tests have been conducted on an experimental transmission line equipped with a counterpoise for reducing the tower footing surge impedance so as to give added protection against lightning. The results of these tests are presented herewith, and should prove valuable to engineers engaged in the design and operation of transmission lines. The desirability of further tests made under a variety of conditions is indicated.

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THE COUNTERPOISE, introduced during the last few years for the protection of power transmission lines against direct strokes of lightning, consists of cables connected to the transmission line towers and buried in the ground. The theory of the counterpoise, a review of past developments, and an analysis of the different types of counterpoises were given in a recent paper (see "Counterpoises for Transmission Lines" by C. L. G. Fortescue, ELEC. ENGG., v. 52, Dec. 1933, p. 908–17).

During the winter of 1933–34 tests were made on an experimental line at the Trafford (Pa.) laboratory with the following objects:

1. To find if the relations between transmission line ground wire and counterpoise are susceptible of measurement using surge generators, cathode-ray oscillographs, and conventional laboratory measurements.

2. To determine, if possible, the effect of leakance on the mutual surge impedance between counterpoise and line and its relation to the depth of the ground plane and the resistivity of the soil.

3. To develop a simple technique of testing so that the electrical utilities may be encouraged to proceed with similar investigations on a larger scale with more diversity in soil conditions, with the hope that with a reasonable expenditure of money the counterpoise problem can be solved in a practical way.

A simple wood pole line was installed consisting of one 4/0 and one 2/0 copper wire on cross arms about 30 ft above the ground at the poles, but considerably higher than this at intermediate points on account of the irregular nature of the ground surface. The line is over 2,000 ft in length and forms a loop starting from the laboratory. A sketch of the plan of the line and its location with respect to the laboratory is shown in Fig. 1. The line was complete and ready for testing about the end of December 1933.

Full text of a paper recommended for publication by the A.I.E.E. committee on power transmission and distribution, and scheduled for discussion at the A.I.E.E. Pacific Coast convention, Salt Lake City, Utah, Sept. 3–7, 1934. Manuscript submitted May 18, 1934; released for publication May 28, 1934. *Not published in pamphlet form.*

TEST I. SURGE IMPEDANCE OF LINES AND MUTUAL IMPEDANCE BETWEEN LINES

These measurements were made by surging one line ungrounded and measuring the current input into the line and the induced potential between the second wire and ground. The measurements of surge impedance made in this manner were calculated at 0.5 μsec intervals (Fig. 3) and then averaged. In Fig. 2 are shown average measurements at different impressed voltages. This curve shows a variation from 450 to 550 ohms. The value of 500 ohms has been taken as fairly representative for the conditions under which the final measurements of the effect of the counterpoise were made.

In Fig. 4 is shown the voltage at pole 2 with both lines ungrounded and, therefore, gives the true coupling factor between the lines. The average of the coupling factors measured at the maximum point of the wave is approximately 0.25, so that if the surge impedance of the surged line is 500 ohms, the mutual surge impedance will be 500 × 0.25 or 125 ohms.

These tests afford a reliable means of obtaining the depth of the equivalent ground plane, and also of checking the value of the surge impedance. Assuming a speed of propagation equal to light, the surge impedance equals $60 \log_e \frac{2(h+d)}{r}$, where h is the height of the wire above ground, d is the depth

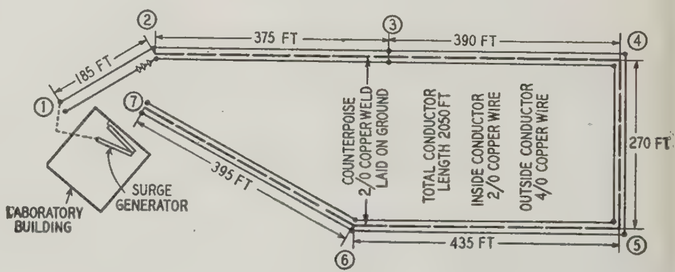


Fig. 1. Plan of wood pole transmission line at Trafford, Pa.

of the ground plane below the surface, and r is the radius of the conductor. Also, the mutual surge impedance for wires on the same horizontal plane a distance d_1 apart equals

$$60 \log_e \frac{2\sqrt{(h+d)^2 + d_1^2}}{d_1}$$

Thus if we know the surge impedance of one of the lines and r and h, d can be obtained. However, because of the presence of corona the effective value for r may be in doubt. For this line, h at pole 2 is

approximately 29.5 ft and d_1 is 10.5 ft. Substituting in the formulas:

$$60 \log_e \frac{2(h+d)}{r} = 500$$

$$\log_e \frac{2(h+d)}{r} = \frac{500}{60} = 8.33$$

$$\frac{2(h+d)(12)}{0.24} = 4{,}225$$

$$h + d = \frac{(4{,}225)(0.24)}{2 \times 12} = 42.25$$

$$d = 42.25 - 29.5 = 12.75$$

The mutual surge impedance was found to be 125 ohms.

$$\log_e \frac{2\sqrt{(h+d)^2 + d_1^2}}{d_1} = \frac{125}{60} = 2.08$$

$$2\frac{\sqrt{(h+d)^2 + d_1^2}}{d_1} = 8$$

$$\sqrt{(h+d)^2 + d_1^2} = 42$$

$$(h+d)^2 = 1{,}764 - 110 = 1{,}654$$

$$h + d = 40.6$$

$$d = 11.1 \text{ ft}$$

If the speed of propagation is less than that of light, then the ground plane depths will be greater.

The correspondence is close enough for practical purposes, and d may be taken as 13 ft in round figures. In the above example, if d_1 had been taken as 11 ft, we would have

$$\sqrt{(h+d)^2 + d_1^2} = 44 \text{ ft}$$

$$(h+d)^2 = 1{,}936 - 121 = 1{,}815$$

$$h + d = 42.6$$

$$d = 13.1 \text{ ft}$$

Hence, an error in d_1 of a few inches will spoil the check. The same is true of the effective radius of the wire. If it is assumed that the surge impedance is affected by the corona radius a correction would have to be made in r, depending upon the corona point of the wire. For example, if the effective radius were 10 per cent larger than in the first example, $(h + d)$ instead of being 42.25 would be 46.5 ft and d would be 17 ft instead of 12.75 ft for the same value of surge impedance.

Test II. Surge Impedance of Ground (Fig. 5)

One of the guy wires with its anchor was used as a footing ground. Its measured ground resistance by megger was 150 ohms. The apparent surge impedance was obtained by inserting a noninductive resistance in series with the ground and measuring the surge potential at the junction point of the resistance and ground, and at the junction point of the resistance and surge generator line. The difference between the 2 readings divided by the resistance gives the wave of the current in the ground, and the potential at the junction of the noninductive resistance and ground is the surge potential. At 0.25 μsec from the zero point of the wave (see Fig. 5) the apparent surge impedance is 240 ohms and at the end of 0.5 μsec it drops to 120 ohms. It is 100 ohms at 0.75 μsec, 90 ohms at 1 μsec, and has an average of about 75 ohms at the crest, from wh ch point it reduces gradual y to about 50 ohms. The record of the test is given in the curve. This is in accord with observations made by other investigators who have made similar measurements with surge generators on high resistance grounds. It is possible that the proximity of large bodies, such as the Trafford laboratory building and the tracks of a branch line of the Pennsylvania Railroad, may be responsible for some of this effect.

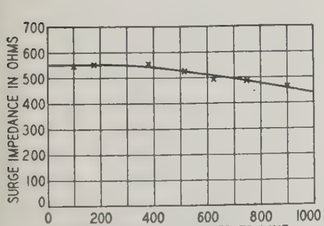


Fig. 2. Surge impedance of No. 4/0 line

(Positive waves)
Points are averages determined by method of Fig. 3

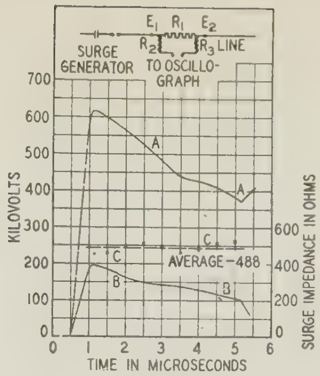


Fig. 3. Typical determination of line surge impedance

Curve A. Voltage applied to line (E_2)
Curve B. Voltage difference across R_1 ($E_1 - E_2$)
Curve C. Surge impedance = $\frac{E_2}{(E_1 - E_2)/R_1 - E_2/R_3}$

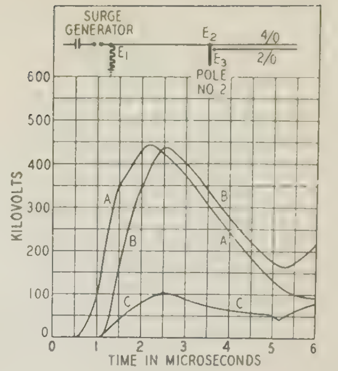


Fig. 4. Determination of coupling factors with open line

Curve A. Voltage at surge generator (E_1)
Curve B. Voltage on 4/0 line at pole 2 (E_2)
Curve C. Induced voltage on 2/0 line at pole 2 (E_3)

Test III. Surge Impedance of Counterpoise (Fig. 6)

The counterpoise consisting of solid $^3/_8$ in. copper weld wire was laid down for the full length of the line over the surface, and only a small portion of it near the pole at which tests were made was lightly covered with earth. This test was made by the same method used for measuring the surge impedance of the ground. The results of this test are shown in the curve of Fig. 6. It will be noted that the apparent surge impedance of the counterpoise is 145 ohms at the end of 0.25 μsec, 80 ohms at the end of 0.5 μsec, 60 ohms at the end of 0.75 μsec, and 45 ohms at the end of 1 μsec, and steadily decreases with time till at 1.75 μsec after the start of the wave it has a value of only 30 ohms. The megger measurement of the counterpoise was 6.0 ohms. The variation in the apparent surge impedance of the counterpoise is a further indication that the earth resistivity is comparatively low, the first indication being the

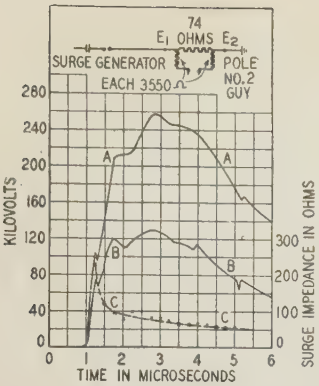


Fig. 5. Determination of surge impedance of pole No. 2 guy

Megger measurement 150 ohms
Curve A. Voltage before resistor (E_1)
Curve B. Voltage applied to guy (E_2)
Curve C. Surge impedance of guy

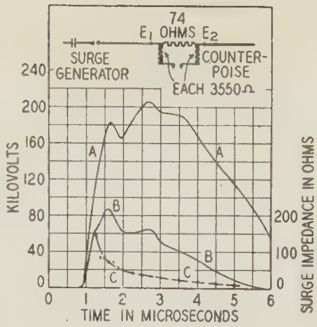


Fig. 6. Determination of surge impedance of counterpoise

Megger measurement 6.0 ohms
Curve A. Voltage before resistor (E_1)
Curve B. Voltage applied to counterpoise (E_2)
Curve C. Surge impedance of counterpoise

small depth of the equivalent ground plane. Under these conditions the effect of leakance cannot be ignored and it will be found that it has a dominating effect on the characteristics of the counterpoise.

Test IV. Coupling Factors (Figs. 7–9)

Test IV consisted of 3 parts, as follows:

(*a*). Line grounded to guy wire alone (Fig. 7).
(*b*). Line grounded to counterpoise alone (Fig. 8).
(*c*). Line grounded to both guy wire and counterpoise (Fig. 9).

These curves show the coupling factors between the line system which receives the surge and the free line, and it will be noted that the introduction of the counterpoise in place of the guy ground has had little influence on the value of the initial coupling factors. This is to be expected for 2 reasons. First, because the depth of the ground plane is very small; the ratio of the distance of the line image in the ground plane from the counterpoise to the distance of the line itself from the counterpoise is of the order of 1.9, the log of which is about 0.64. If the ground plane were at ground level the mutual surge impedance would be zero and as it approaches ground level the mutual surge impedance becomes smaller and smaller. Second, the low resistivity which is associated with a small depth of ground plane produces distributed leakance, which may be looked upon as producing positive reflections of current which have the effect of reducing the mutual surge impedance potential due to the positive current surges moving in the normal direction while at the same time they decrease the apparent surge impedance of the counterpoise.

Test V. Coupling Factor With Counterpoise Placed in Air (Fig. 10)

Test V is the same test as IV(*b*) with counterpoise raised 6 ft above ground level (see Fig. 10). This test was made to show the effect of placing a counterpoise in air. It will be noted that the presence of the counterpoise has increased the coupling, as was to be expected, because now the counterpoise is closer to the line wire and further from its image, also the effect of leakance is eliminated. The net result, however, is a distinct loss of effectiveness of the counterpoise, resulting in higher potentials of the ground wire and larger difference of potential between the line and ground wire. Theoretically, if the line wire could be completely enclosed with ground wires spaced fairly close together and connected together at frequent intervals, protection approaching the ideal in which line wires and ground wires would have the same potential under all conditions would be approached. This is, however, impossible to achieve in practice and it seems that

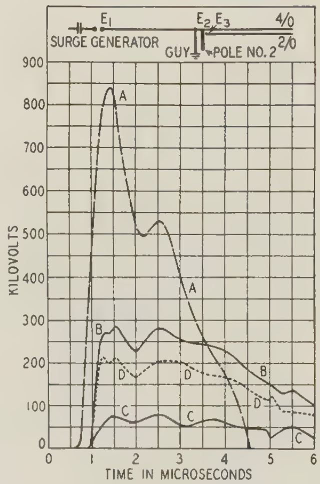


Fig. 7. Determination of coupling factors with guy connected

Curve A. Voltage at surge generator (E_1)
Curve B. Voltage on 4/0 line at pole 2 (E_2)
Curve C. Induced voltage on 2/0 line at pole 2 (E_3)
Curve D. Voltage difference between lines ($E_2 - E_3$)

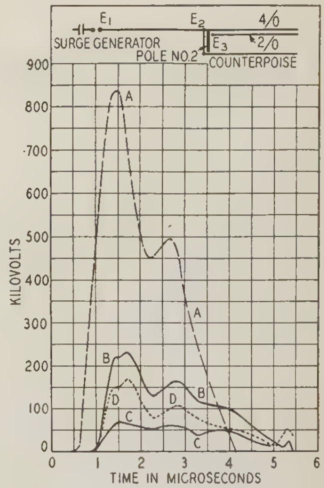


Fig. 8. Determination of coupling factors with counterpoise connected

See subcaption of Fig. 7 for meaning of curves

the best procedure is to take advantage of the lowered surge impedance obtained by burying the counterpoise in the ground.

Test VI. Experimental Tests With Parallel Wires Laid on the Ground to Determine Specific Resistance of the Soil

The results of these tests are given in Table I. To obtain the specific resistance from these values the formula for the resistance per unit length between 2 parallel conductors in homogeneous conducting mediums may be used. The approximate formula is

$$\text{Resistance per unit length} = \frac{1}{\pi}\rho \log \frac{2d}{r}$$

In this formula $2d$ is the distance between the centers

of the wires, r is the radius of the wires, and ρ is the specific resistance in the same units as are used for the measure of length; for example, if the length is in meters, ρ is in ohms per meter cube. In the case with which we are dealing the center line between conductors divides the 2 mediums, earth having a resistivity ρ, and air having infinite resistivity. This condition gives

$$\text{Resistance per unit length} = \frac{2}{\pi}\,\rho \log \frac{2d}{r}$$

Using this formula we obtain:

Test No. 1. ρ = 727.5 per foot cube
= 222 per meter cube

Test No. 2. ρ = 376 per foot cube
= 114.5 per meter cube

Test No. 3(a). ρ = 487 per foot cube
= 148 per meter cube

Test No. 3(b). ρ = 448 per foot cube
= 137 per meter cube

All these tests were made under different weather conditions. In test No. 1 the soil was comparatively dry. In test No. 2 it was thoroughly water soaked. In test Nos. 3(a) and 3(b) it was comparatively moist. End effects have been ignored in all cases.

The object of these tests was to determine whether this simple method of arriving at ρ for the top soil would give reliable results. The fact that tests 3(a) and 3(b) give comparable results is encouraging and suggests that further tests along these lines should be made. It is believed that in the lightning protection of transmission lines the actual penetration is relatively small, with the surge currents actually spreading over the surface of the earth, and it is this surface distribution that gives the effect of penetration. For this reason the resistivity of the surface soil may be of great importance. The values of ρ obtained may be classed as medium values. High values are of the order of 10,000 ohms per meter cube, and low values of the order of 2 or 3 ohms per meter cube.

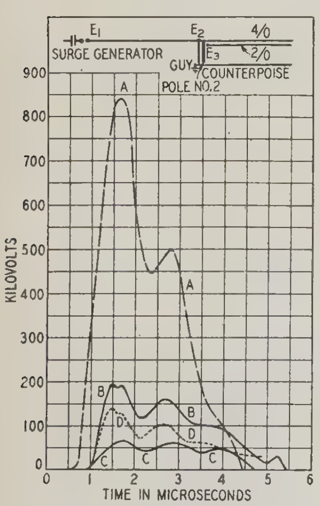


Fig. 9. Determination of coupling factors with counterpoise and guy connected

See subcaption of Fig. 7 for meaning of curves

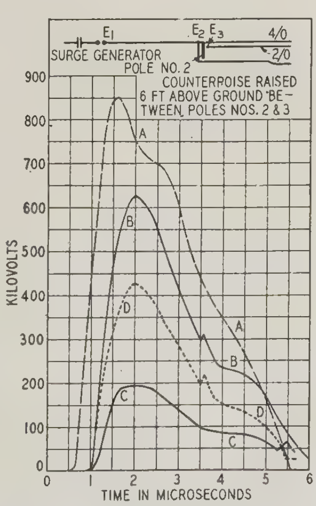


Fig. 10. Determination of coupling factors with counterpoise raised

See subcaption of Fig. 7 for meaning of curves

Test VII. The Use of the Surge Generator in Simulating a Lightning Discharge to a Line

Where a lightning stroke strikes a transmission line wire it has become the practice to consider the lightning channel to have a surge impedance Z_0 to which has been ascribed values varying from 200 ohms to 400 ohms. If the effective surge impedance of the line to the surge from the stroke is Z_1 and E_0 is the potential of the lightning surge and E_1 that of the surge on the line resulting from the stroke then

$$\frac{E_0}{E_1} = \frac{Z_0 + Z_1}{2Z_1}$$

In measuring the surge impedance of such a line a known noninductive resistance is placed in series with it and the surge generator, and the surge potential at the junction point of the line and resistor and at the other terminal of the resistor are measured. Let these values be E'_1 and E'_0, respectively, and let the value of the resistor be R_0. Then we have

$$\frac{E'_0 - E'_1}{R_0} = \frac{E_1}{Z_1}$$

or

$$\frac{E'_0 - E'_1}{E_1} = \frac{R_0}{Z_1}$$

$$\frac{E'_0}{E_1} = \frac{R_0 + Z_1}{Z_1}$$

In order, therefore, that the ratio of $\frac{E'_0}{E_1}$ shall represent actual surge conditions for a given value of Z_1

$$\frac{R_0 + Z_1}{Z_1} \text{ must equal } \frac{Z_0 + Z_1}{2Z_1}$$

or

$$R_0 + Z_1 \text{ must equal } \frac{Z_0}{2} + \frac{Z_1}{2}$$

or

$$R_0 \text{ must equal } \frac{Z_0}{2} - \frac{Z_1}{2}$$

For a composite circuit consisting of short lengths of transmission of different values of surge impedance

Table I—Ground Resistance Measurements Between Parallel Conductors Laid 2 In. Below Surface

	Volts	Amperes	Ohms Resistance
Test No. 1—Weather Fair; Conductors 25 Ft Apart, 127 Ft in Length			
Alternating current	110	4.1	26.8
Direct current	118	3.8	31.0
Test No. 2—After 12 Hr Rainfall; Conductors 25 Ft Apart, 127 Ft in Length			
Alternating current	104	7.5	13.9
Direct current	120	7.0	17.2
Test No. 3(a)—Weather Fair; Checking Conductors 25 Ft Apart, 127 Ft in Length			
Alternating current	104.5	5.8	18.0
Direct current	120.0	5.7	21.0
Test No. 3(b)—Weather Fair; Conductors 68 Ft Apart, 127 Ft in Length			
Alternating current	105	5.55	19.0
Direct current	127	5.8	21.9

Z_1 cannot be considered constant so that the value of R_0 must be determined for the value of Z_1 which is dominant at the instant of time in which we are interested.

Tests were made in accordance with this theory, the results of which are shown in Figs. 11 and 12. In analyzing these curves it must be remembered that the conductor used as a ground wire is only 30 ft above ground at the pole, whereas usually the height of most ground wires of steel tower transmission lines is from 80 to 100 ft above ground at the tower. The surge impedance of the steel tower itself is of the order of 100 ohms. In the experimental line, the down drop lead and the guy wire have

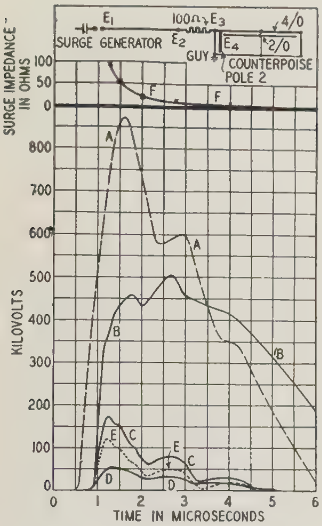


Fig. 11. Determination of coupling factors with 100 ohms series resistance

See subcaption of Fig. 12 for meaning of curves

probably a surge impedance of several times this value. This higher surge impedance does not compensate for the lower level of the ground wire except possibly in connection with the magnitude of the potential obtained, but on account of the low level the maximum magnitude will be reached in much less time, and this is what the curves indicate. For example, in Fig. 12 the crest of the ground wire potential is reached in 0.5 μsec although the wave E_2 is still increasing. However, on account of the high surge impedance of the down drop grounding lead it is probable that the crest value obtained is approximately the same as would exist on a normal tower after 1 μsec. The surge impedance values are therefore higher than would be recorded on a normal steel tower line and the rate of decrease is higher.

The resistance used is based upon the supposition that at the point of test the portion of the line affected is only one-half the portion that would be affected by a lightning stroke. In other words, the counterpoise and ground wires would normally extend in 2 directions, 2 guy wires would represent the normal ground, and there would be 2 down drop leads having a combined surge impedance equal to one-half of the lead used. Under these conditions Fig. 12 gives the values that would be obtained if the surge impedance of the lightning stroke were approximately 250 ohms at the start and became finally 200 ohms. There does not appear to be anything unreasonable in such an assumption if we wished to make it, but it is much easier to make calculations on the basis of a fixed value of Z_0 and 200 ohms has been generally used. On the basis of 200 ohms with conventional towers and a footing resistance of 15 ohms the calculated value of maximum tower top potential reached in 1 μsec with the same surge impressed as in A would be approximately 112 kv as against 117 kv shown by the test. However, at the end of 2 μsec after the start of the wave the calculated value will be 72 kv whereas the curve shows only 27 kv. The effect of the counterpoise appears to be to increase the attenuation of the tower top potential. The total currents indicated by the curve are of the right order; thus, for example, after 2 μsec the current is $\frac{540{,}000 - 27{,}000}{195}$ or 2,630 amp. In terms of 20,000 kv the current would be 97,500 amp, but this is the current in half the line only so that the total current at 20,000 kv would be 195,000 amp, which agrees with the maximum surge currents that have been observed in field tests. The energy in a 20,000-kv lightning stroke has about 5,500 times the energy of the surge shown in these curves. The values obtained from Fig. 12 extrapolated to 20,000 kv are probably pessimistic.

It would be very instructive if the tests given in these curves could be duplicated on an actual transmission line. Small scale models are not appropriate as there is no way of scaling down the velocity of propagation of surges in proportion to the scale of the model; this fact has been lost sight of in the past and many erroneous ideas have resulted from laboratory tests on models. Tests made on selected locations would be of incalculable benefit to the electrical industry as they would undoubtedly clear up all of the puzzling inconsistencies that have been encountered in the past; newly built lines could be tested and their performance predicted before they were put in service, poorly behaving old lines could be diagnosed and in many cases corrected.

While it would not be proper to draw broad conclusions from the results of these tests, it is felt that the results are of sufficient promise to justify further investigation along the same lines on a larger scale.

Table II—Speed of Propagation

Using line open at far end and shorted at surge generator with sphere gap which causes a steep chopped wave. Length of line 2,190 ft

Oscillogram	Microseconds: Time for first reflection	Time for second reflection	Time for third reflection	Time for fourth reflection
1. One complete reflection	5.0			
2. One complete reflection	5.0			
3. Three reflections	5.0	5.1	5.9	
4. Three reflections	5.0	5.0	5.0	
5. Four reflections	5.0	5.0	5.6	5.4
6. Four reflections	4.8	4.6	5.0	5.0
Average	5.1			

Speed $= \frac{(2{,}190)(2)}{5.1} = 860$ ft per microsecond (87.5 per cent of speed of light)

Test VIII. Velocity of Propagation of Waves Over Line

A check of the velocity of propagation over the line was made by using a chopped wave which traveled back and forth along the line. Positive reflections occurred at the open receiving end, and negative reflections at the grounded sending end. Oscillograms recorded the period of these double reflections (see Table II). The average of the values obtained from these tests indicated a velocity of propagation 87.5 per cent of that of light. This difference is probably explained by the fact that the line is very low and the resistivity and dielectric constant of the earth have an appreciable effect. With higher resistivity soil this effect might be expected to be more pronounced.

Discussion of Tests

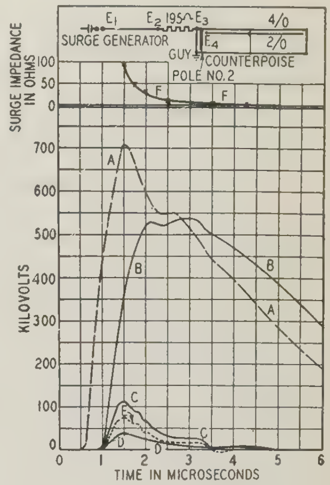
The first fact that was encountered when Test I was carried out was the small depth of the equivalent ground plane. This was not at all what was expected from the geological nature of the site on which the transmission line was installed. However, Test VI seems to confirm the results of Test I by indicating that the top soil has comparatively low resistivity and for further confirmation the surge impedance of the guy anchor ground and the character of the impedance of the counterpoise are what would be expected with comparative low soil resistivity.

In considering the adequacy of the ground used as a reference from which to measure potentials and that of the actual ground for the surge generator, we must consider to a certain extent the mechanism of the lightning stroke. The cloud and the earth form 2 capacities and the earth may be considered infinite and practically at zero potential so long as there are no discharges. An electric field exists between the cloud and the earth which is affected by any discharge from cloud to earth. The charges on the earth's surface due to the charge on the cloud may be considered as caused by the charges in the cloud and their image in the surface of the earth. This would give the correct distribution if the earth were a perfect conductor, but since this is not so, the field of the cloud penetrates into the earth some distance and while the surface distribution will generally preponderate, any change in the charge of the cloud will produce a volume distribution penetrating some distance into the earth, the depth of penetration being greater the greater the resistivity of the earth in the region affected by the cloud field. When the cloud starts to discharge to earth, displacement currents take place in the cloud and similar conduction and displacement currents take place in the earth, which are associated with the charge in the field of the cloud caused by the streamer. When the streamer reaches the earth, charge rushes in from all parts of the earth causing changes in surface and volume distributions to annul the charge conveyed by the lightning channel and these movements of the charge distribution constitute the conduction and displacement currents in the earth and from the earth to cloud, and the complete circuit formed thereby carries a total current equal to the lightning discharge current at the earth's surface.

From the above it will be evident that there will be considerable difficulty in obtaining a ground for the surge generator that will give the same distribution of earth currents that is obtained with a natural lightning discharge. On the other hand, if the surge generator ground impedance is low, the current passing through it may be considered as derived from a very large area which may be comparable with that through which the movements of charges in the earth associated with a lightning stroke take place. The

Fig. 12. Determination of coupling factors with 195 ohms series resistance

Curve A. Voltage at surge generator (E_1)
Curve B. Voltage at pole 2 before series resistance (E_2)
Curve C. Voltage on 4/0 line at pole 2 (E_3)
Curve D. Induced voltage on 2/0 line at pole 2 (E_4)
Curve E. Voltage difference between lines ($E_3 - E_4$)
Curve F. Surge impedance of line, guy, and counterpoise



laboratory ground used in these tests is connected to the water mains supplying the building, to the metallic structure of the building itself which has a large capacity, and also to the large oil tanks which are connected to the oil drainage system. It covers an area, therefore, of large surface contact with the earth and having high capacitance, and fulfills fairly well the conditions for distribution of the surge current in the earth. It should be remembered also that the high potentials existing in the earth due to a lightning stroke are highly localized and even at a distance of a hundred feet or so the potentials are reduced to relatively small values. It does not seem likely that where the resistivity of the soil is very high the direction of flow of the earth currents will influence to any great extent the propagation of the surges in the counterpoise wire itself. With low resistivity soil the magnitude of the currents in the earth may become large and if their direction is opposite to that of the propagation in the counterpoise they may have a considerable effect on its apparent behavior. In considering the results of these tests, therefore, weight must be given to the possible effects of the location of the laboratory with respect to the line and the position of the surge generator ground.

Let us consider Tests IV(a), (b), and (c); these were made under the same weather conditions and therefore are comparable. It should also be noted that the line used for the ground wire is grounded only at pole No. 2, being open at the far end. The fact that the line is open at the far end need not concern us as the reflection will not have any effect until

after 5 μsec from the start of the wave. However, with no ground at poles 1,000 ft distant the potential recorded is higher after 2 or 3 μsec than it would have been had the line been grounded at a distance of 1,000 ft from pole No. 2. First of all, it should be noted that the wave impressed at the generator terminals is practically identical in the 3 tests. Next it will be noted that the coupling factor for (*a*) is about 29 per cent, for (*b*) about 32 per cent, and for (*c*) about 34 per cent. The results for (*b*) and (*c*) appear to be inconsistent as far as coupling factor is concerned, but this easily may be accounted for by the point on the wave at which the values were read. In general, it will be seen that the inclusion of the counterpoise has affected the coupling factor a very little.

The next thing to observe is the maximum value of the potential difference between line and ground wire. This shows the following values:

(*a*). With guy wire ground alone, 212.5 kv.
(*b*). With counterpoise alone, 170.0 kv.
(*c*). With both guy and counterpoise, 142.0 kv.

It will be noted that the counterpoise shows considerably (20 per cent) better than the guy wire and the 2 together are about 16 per cent better than the counterpoise alone and 33 per cent better than the guy wire ground alone. But there is considerably more gain than is indicated by the maximum values alone. In the first case (*a*) the difference of potential at the end of 2 μsec duration of the wave is about 93 per cent of the maximum, and at the end of 3 μsec the difference is 77 per cent of maximum; with the counterpoise alone (*b*) at the end of 2 μsec of wave the value of the potential difference is only about 58 per cent of the maximum, and at the end of 3 μsec it is about 31 per cent of its maximum. With both guy and counterpoise (*c*) at the end of 2 μsec of the wave the value is 57 per cent of the maximum and at the end of 3 μsec of wave it is 31 per cent of the maximum. Thus it is evident that the counterpoise has attenuated the wave of potential difference to a great amount compared with the guy ground, with corresponding improvement in protection.

In spite of the fact that the soil resistivity is quite low, a condition which is not particularly favorable to the counterpoise, it has shown a decisive gain. It is probable, however, that the same results might have been obtained by the use of several driven grounds. On the other hand, it is probable that 200 ft of counterpoise would have given just as good results as the full length which was used. With higher resistivity soil the counterpoise will show up more effectively due to the greater depth of the ground plane and lower leakage, which will give a high mutual surge impedance between counterpoise and ground.

Further Investigation

The results of these tests show that a technique has been worked out which it is believed will give approximately the characteristics of counterpoise grounds under any soil conditions. There is urgent need for more data on the performance of counterpoises under varying soil conditions. After such data have been obtained it will be an easy matter, knowing the soil resistivity, to design a counterpoise system which will be adequate. On the other hand, some method must be developed for finding out whether a counterpoise is needed or whether the same results may be obtained more economically by the use of driven grounds. It is believed the proper procedure for obtaining the required data is to build a section of wood pole line 2,000 or 3,000 ft long of similar construction to that at the Trafford laboratory, except that better arrangements for grounding one of the lines should be provided, so that lower surge impedance of the grounding lines may be obtained. The work would be done at the center of the line so that a grounded tower 1,000 ft away on either side will be available. In order to obtain results more or less directly comparable with actual lines, 3 wires are suggested so that 2 of them may be used for overhead ground wires, while the third will be the line wire and left free for mutual coupling measurements. The counterpoise may be made up of any suitable material in suitable lengths, say 200 or 100 ft, and provision can be made for connecting links so that it may be laid down as a single parallel counterpoise over the whole length of the line, or by removing a section the counterpoise may be made to extend on either side of the tower 100 or 200 ft or they may be laid down to form a double parallel counterpoise or cross counterpoise.

On account of the fact that the test should be made at the middle of the line instead of at one end as was done in the Trafford test, an extra large surge generator should be used because the load on the surge generator will be twice as great as in the Trafford tests. A 2,000-kv generator of 0.025-μf capacity would be satisfactory. Difficulty may be experienced in obtaining a reference ground for the surge generator of sufficiently low surge impedance where the resistivity of the soil in the test location is high. This problem will have to be worked out in the field for each location. Once this ground is established there will be no difficulty in carrying out the necessary tests on the line. A program of the kind discussed above is very essential if the art of transmission of power is to progress.

Conclusions

The following conclusions appear to the authors to be justified from these tests.

1. Measurements can be made from which the surge impedance of ground wires, counterpoise wires, grounds, and the mutual coupling factors between these and line wires can be derived for use in calculations.

2. The depth of the equivalent ground plane may be deduced from some of these measurements.

3. The results of these tests indicate that small depth of ground plane and low resistivity of the soil are related characteristics. They reduce the coupling factor between counterpoise and line.

4. The relation between coupling factors of counterpoise and line as affected by the depth of the ground plane seems clear, but the effect of leakance due to low earth resistivity will require more data with diverse soil conditions.

5. Leakance appears to be the dominant quantity in determining the effectiveness of counterpoises when the soil resistivity is low.

Further investigation of like character will be required to determine at what values of soil resistivity counterpoises instead of driven grounds are indicated.

6. The tests indicate that counterpoises even in comparatively low resistance soil are effective not so much by reducing the maximum value of the tower top potential as by reducing the tail of wave in a very marked manner so that the energy in the wave is very much reduced.

7. A method of obtaining the resistivity of the top soil has been derived and gives what appears to be satisfactory results.

8. A method of testing a complete line to simulate the effect of a lightning stroke over a channel having a given value of surge impedance was tried out. This method although not rigorous holds great promise as a means for comparing the advantages of different types of grounding, and comparing them with known types. It also may be used in testing new lines to determine their probable future behavior.

9. A more comprehensive program of testing should be carried out at locations having different soil conditions to determine the characteristics of counterpoises and other grounding means.

Field Tests on Conductor Vibration

Field tests on transmission conductor vibration as affected by dampers and suspension clamps have been made in an attempt to find a solution to the important problem of stopping such vibration in an economical manner. This paper presents some data in regard to number and spacing of the "Stockbridge" type damper. The question of whether vibration is transmitted through or stopped by various types of suspension clamps also is discussed, and actual records of frequencies on both sides of suspension clamps shown.

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MUCH valuable information has been obtained, both from the laboratory and field, on vibration of transmission line conductors. The theory, cause, effect, and methods of preventing trouble from conductor vibration has been presented from many angles over a number of years. This paper will not attempt to discuss the theory or cause of vibration, but will present records, taken on an operating line over a period of several months, with and without damping equipment, in the hope that these records will help some of the many engineers now studying this problem to understand better what actually occurs in the field.

The tests were made:

1. To determine the damping effects of different numbers and spacings of the same type of damper in any one span.

2. To get records of the actual frequency and amplitude of the vibration occurring on the conductor.

3. To get simultaneous records of the actual frequency and amplitude occurring in adjacent spans.

4. To compare the action of trunnion and non-trunnion type clamps on the bending of the conductor, by taking simultaneous frequency and amplitude records equidistant on each side of the clamp.

The tests were made on a 165-kv circuit of 795,000-cir-mil aluminum conductor steel reinforced, having 54 strands of aluminum, 0.1214 in. diam., and 7 strands of steel, 0.1214 in. diam. The circuit was operating on one side of a twin circuit steel tower line having a normal span of from 750 to 800 ft. (229 m to 244 m). The tension in the conductor was approximately 4,100 lb (1,860 kg) at 60 deg F.

Instruments

Many instruments have been made to record amplitude of vibration, by attaching them directly to a "dead" line, or by connecting to a "hot" line with an insulating string, but this method requires bulky equipment and tends to confine the test to one locality or restricts the number of records obtained. With portability and a large number of records in mind, an instrument shown in Fig. 1 quite similar to a smaller one used by the Aluminum Company of America, was adapted for the purpose. This instrument in its original form was used to record time of operation of motor vehicles and consisted of

Full text of a paper recommended for publication by the A.I.E.E. committee on power transmission and distribution, and scheduled for discussion at the A.I.E.E. Pacific Coast convention, Salt Lake City, Utah, Sept. 3–7, 1934. Manuscript submitted April 30, 1934; released for publication May 24, 1934. *Not published in pamphlet form.*

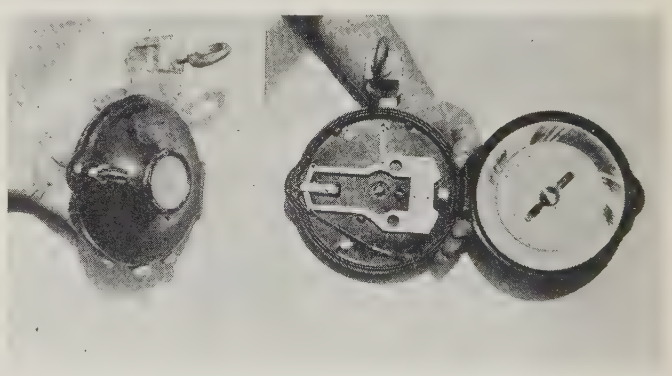


Fig. 1. Two views of recorder "A," used to record time and amplitude of vibration

a light pendulum with a stylus attached to it. This stylus recorded the movement of the pendulum on a 6 in. (15.2 cm) diam. circular waxed chart which was driven by means of a clock. For recording vibration, the instrument was rotated 90 deg in the plane of the pendulum and the latter held in a horizontal position with a light spring. The instrument was then hung on a mechanically vibrated conductor and the weight of the pendulum and distance of the stylus from the axis of the pendulum altered until the chart record represented the vibration amplitude to very near actual scale at all frequencies from 3 to 30 cycles per second. By making all but the clock parts out of aluminum, the weight was kept down to 3.5 lb (1.59 kg). Seven of these instruments were made and were put on and taken off the conductor with a "hot stick" 12 ft (3.66 m) long. Several checks made in the field showed the amplitude of vibration recorded to be remarkably close to the actual. This instrument will be referred to as recorder A.

Another instrument was adapted to record frequency and amplitude for 3 independent motions

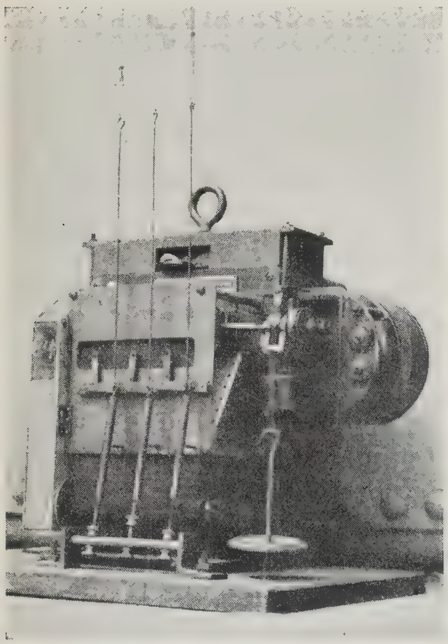


Fig. 2. Recorder "B" with alternate low and high speed chart drive

Simultaneous vibration records taken from 3 different points. Note beam between the 2 outside strings with center point attached to center recording arm for recording the resultant of the outside motions

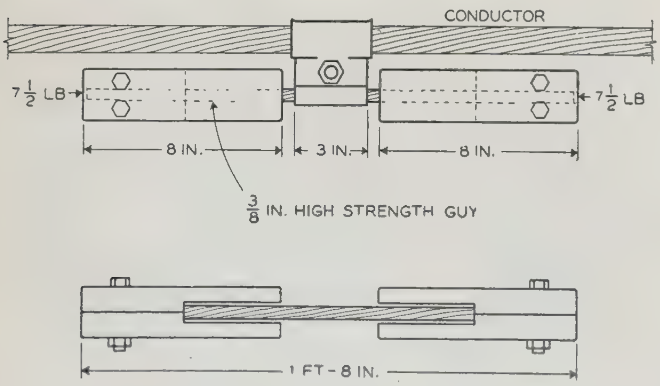


Fig. 3. "Stockbridge" type damper used in test, showing above, elevation of damper, and below, plan of damper without clamp

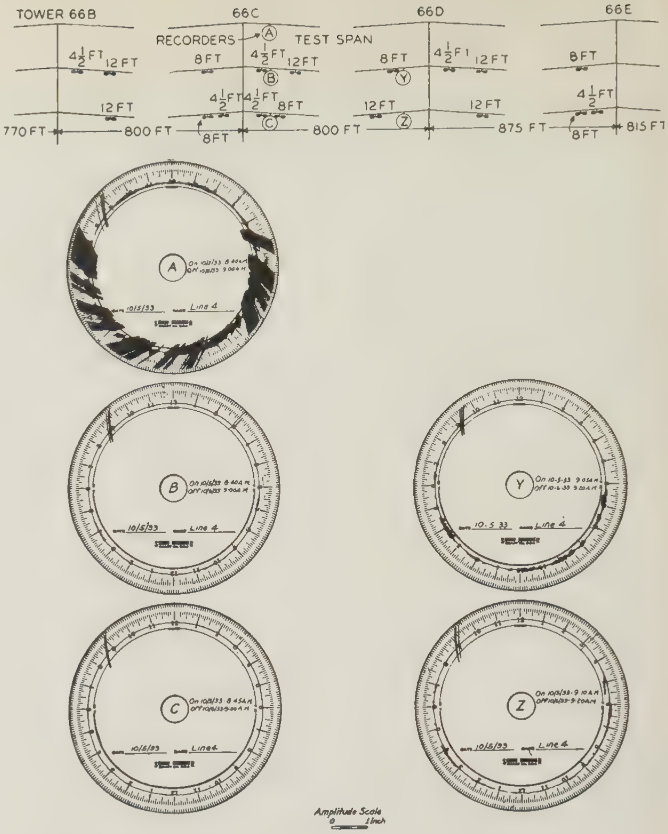
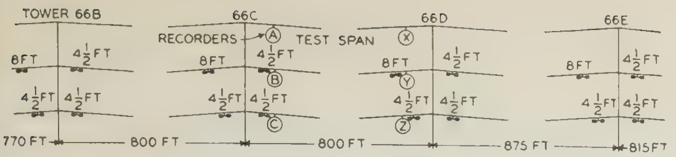


Fig. 4. Charts from recorder "A" showing amplitude of vibration on conductors with 2 arrangements of 2 dampers per span

	A	B	C	Y	Z
On, 10/5/33, a.m.	8:40	8:40	8:45	9:05	9:10
Off, 10/6/33, a.m.	9:00	9:00	9:00	9:20	9:20

simultaneously on one rolled strip chart. Three small cranks, with equal length arms, were mounted on the face of an Esterline Angus quick-trip high-speed motor-driven recorder as shown in Fig. 2. The horizontal sections of 2 of these arms were attached directly to the conductor with a special waxed twine, at positions within 20 ft (6.1 m) of each other. The end of the vertical section of the crank arms held a stylus which recorded the movement of the end of the arms on the moving chart. The chart was standard paper roll which had been sprayed with a black crackle enamel. Marks made by the steel stylus could be seen easily by light reflection. Moderate speed clock drive, and fast electric motor speed drive were used alternately for long periods of operation. Amplitude was recorded continuously at both speeds but readable frequency also was recorded at the fast speed for short periods only every half hour. This instrument was designed primarily to obtain simultaneous readings of vibration in the conductor on each side of the suspension clamp. A small aluminum beam was connected between the 2 outside strings, and the center of this beam was attached to the middle crank arm to obtain the resultant of the 2 outer string vibrations. The resultant is equal to one-half the algebraic sum of the 2 vibration motions. This instrument will be referred to as recorder B.



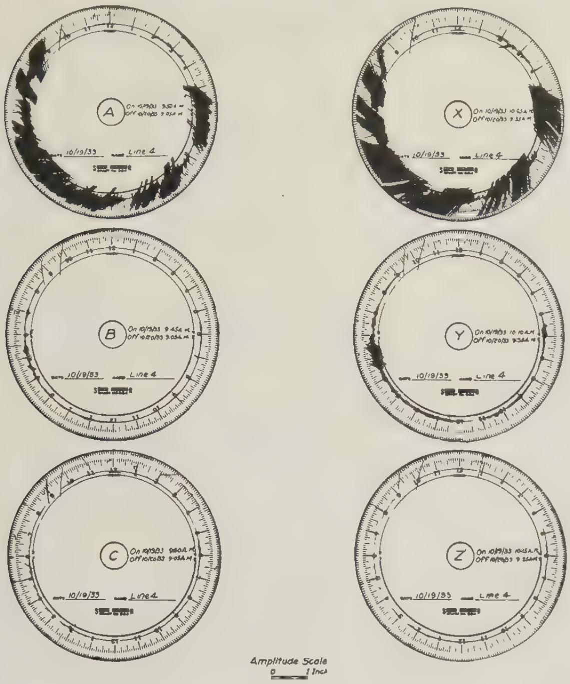


Fig. 5. Charts from recorder "A" showing amplitude of vibration on conductors with 2 arrangements of 2 dampers per span

	A	B	C	X	Y	Z
On, 10/19/33, a.m.	9:50	9:45	9:40	10:05	10:10	10:15
Off, 10/20/33, a.m.	9:05	9:05	9:05	9:35	9:35	9:35

Damper Tests

Many preliminary records were taken on the line to determine the frequency and amplitude of vibration. During these tests, covering approximately 1,000 continuous hours, it was found that vibration occurred over 80 per cent of the time at amplitudes from 0.1 in. (5 mm) to at least 0.9 in. (2.38 cm) which was the maximum travel limit for recording of the stylus in the recorder *A*. As a result of these preliminary tests, an exposed position of approximately 6 miles (9.67 km) near Sacramento, Calif., was chosen for the vibration damper tests. At this place, the line location is almost due north and south, and about 20 miles (32.2 km) from the eastern side of the southern end of the Sacramento Valley. The valley is about 60 miles (96.7 km) wide at this point. Prevailing winds were generally from the west across the line toward the Sierra Nevada mountains, during the time of test between June and October.

The damper chosen for test was the "Stockbridge" type, as shown in Fig. 3.

Experiments were made in the year 1932 on another line having the same type of conductor, and as a result 4 dampers per span, spaced 4.5 ft (1.37 m) and 12 ft (3.66 m) from the suspension clamp on one end, and 8 ft (2.44 m) and 15 ft (4.57 m) from the suspension clamp on the other end of the same span were installed.

The purpose of the present tests was to determine the best position and the minimum number of dampers which could be used in each span to sufficiently damp the vibrations.

In the tests described in this paper, several damper installations were made along the line, each being separated from the others by at least 3 undamped spans. All combinations of the above spacings were installed, and at each location, one conductor, usually the top, was left undamped, while the middle and bottom wire were damped with the experimental arrangement. Recorders type *A* were placed on the undamped wire at one end, and on the middle and bottom wires at both ends 6.0 ft (1.84 m) from the suspension clamps. The undamped wire record was

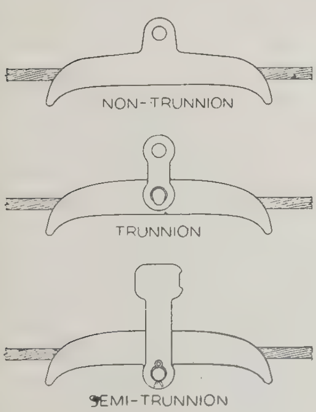


Fig. 6. Three types of suspension clamps used in test

Fig. 7. Frequency curve, showing number of times any frequency occurred over a long period of time

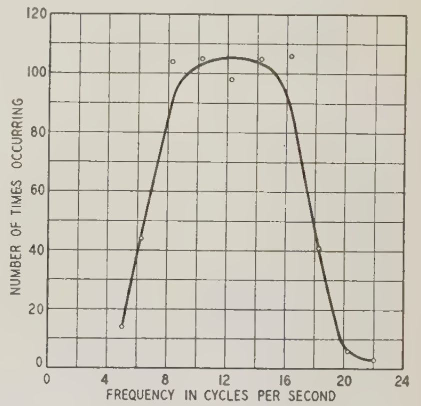
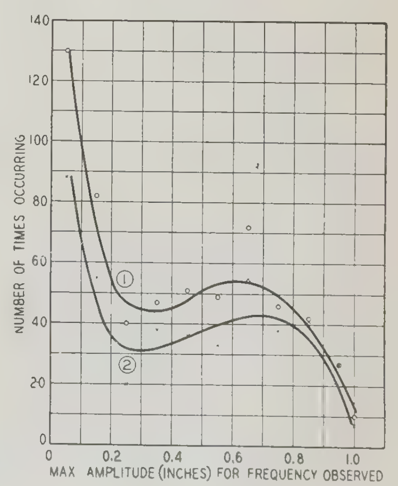


Fig. 8. Amplitude curves, showing number of times any amplitude occurred

Curve 1. Number of times occurring during test
Curve 2. Number of times occurring at frequencies 8 to 16 cycles per second



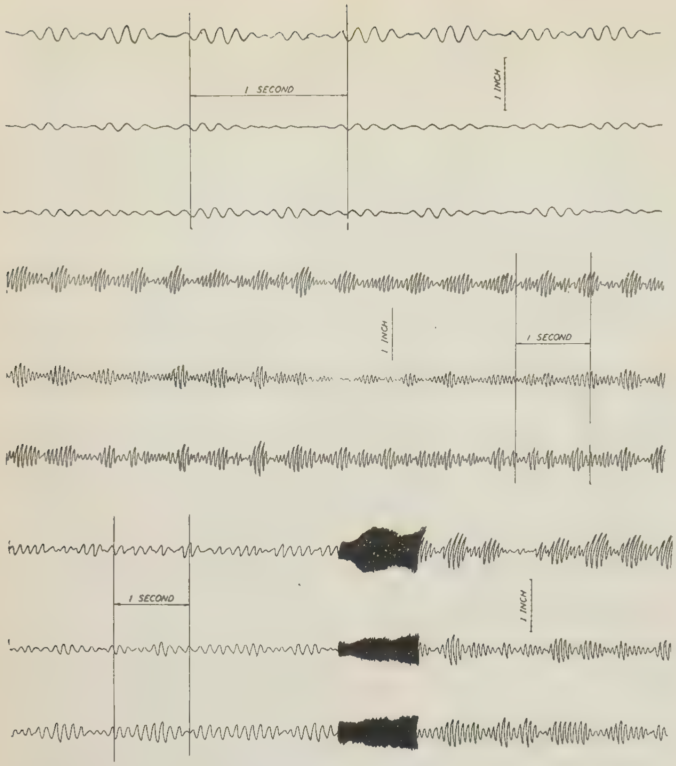


Fig. 9. Three amplitude and frequency charts, taken with recorder "B" on trunnion type clamp

Top and bottom curves of each chart from opposite sides of the clamp 5 ft out
Middle curve of each chart is the resultant. (See Fig. 2)
Solid sections taken at clock speed for 30 min
Frequency curves taken at motor speed (shown by the horizontal scale) for 12 sec at the end of each half hour
Amplitude shown by vertical scale

used as an indication of the probable vibration which would have occurred on the other 2, if dampers had not been attached to them. From 4 to 8 24-hr records were taken on each installation. The records from the damped wires were compared with each other and by elimination the better arrangements were set up again, this time with dampers installed in the adjacent spans, to prevent interference from those heretofore undamped spans. Records taken from 2 of the better arrangements are shown in Figs. 4 and 5. These records were taken from several of the same type and are distinctly representative.

Suspension Clamp Tests

The purpose of this test was to get a large number of simultaneous records of frequency and amplitude of conductor vibration on both sides of 3 different types of suspension clamps. The clamps used were standard makes of the non-trunnion, trunnion, and semi-trunnion types shown in Fig. 6. The insulator string consisted of 14 10-in. (25.4-cm) ball and socket, 5.75-in. (14.6-cm) spaced cap and pin type insulators. Records were all taken with the recorder B installed in the tower approximately 15 ft (4.57 m) below the bottom conductor. Waxed strings were attached to the conductor on each side of the suspension clamp at points 5 ft (1.52 m) out from its center. These

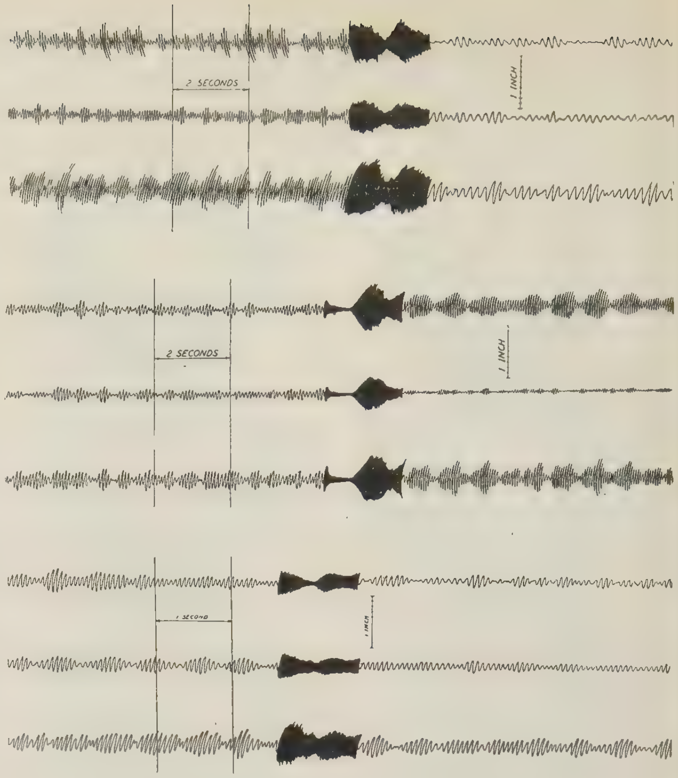


Fig. 10. Three amplitude and frequency charts, taken with recorder "B" on semi-trunnion clamp

See subcaption of Fig. 9 for meaning of curves

strings were dropped vertically to the end of high strength aluminum tubes supported horizontally, and from the end of these over small ball bearing aluminum sheaves through the tube to the recorder B. A short distance above the recorder B, a light metal beam was connected between the 2 strings, and its middle point connected with a light stiff wire to the middle crank arm. The amplitude of the vibration recorded by this middle crank stylus point indicated quite accurately whether the vibrations in one span were or were not synchronous and in phase with those in the adjacent span.

The records taken on the above set-up also furnished some very useful information as to the frequencies actually occurring on the conductor over a long period of time; the comparative frequencies and vibration amplitude occurring in adjacent spans; and the effect, if any, of the different type of clamps on frequency and amplitude.

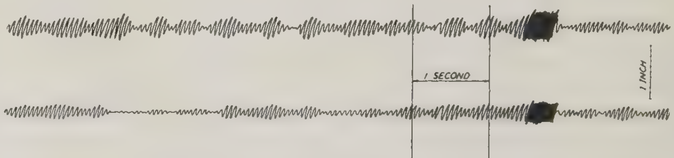


Fig. 11. Amplitude and frequency charts, taken with recorder "B" on non-trunnion clamp

See subcaption of Fig. 9 for meaning of curves

The frequency occurring on the conductor for all records taken is shown in Fig. 7, and indicates quite a broad range on this particular conductor. Most of the records were taken between 5 p.m. and 8 a.m. as but little vibration occurred during the remainder of the time. In Fig. 8 are shown 2 curves of amplitude plotted against number of times occurring. The amplitude referred to is that occurring at a point 5 ft (1.52 m) from the suspension clamp.

The frequency occurring in adjacent spans was generally about the same, being in almost all cases within 1 or 2 cycles per second of each other. In a few cases the frequency in one span was approximately one-half that in the other. Some cases were observed, however, where there was little or no vibration recorded in one span, while the adjacent span was quite active, reaching amplitudes of 0.5 in. (1.27 cm) or over at times. In general, the amplitude and frequency characteristic of one span was similar in some respect to that in the adjacent span.

Charts shown in Figs. 9, 10, and 11 are representative sections taken from the records on the 3 types of clamps. The top and bottom curves represent the vibration of the conductors from opposite sides of the clamp. The middle curve is the resultant or half the algebraic sum of the top and bottom curves, as indicated by the motion of the middle point of the beam shown in Fig. 2. The records were taken at various speeds of the clock, or motor drive, but may be studied by means of the scales shown. A comparison of the wave form of the conductor vibration for any instant taken from either side of the clamp will indicate what the resultant vibration should be. For all cases studied closely, this checked exactly with that recorded. A study of all records taken gave no indication of any consistent effect given by any certain type of clamp. All the records of frequency and amplitude, regardless of type of clamp, showed a consistent inconsistency. Most of the records studied showed an indication that the vibration in one span tended to break up the vibration in the adjacent span regardless of the type of clamp used. This was shown by the occasional sudden change in the uniformity of cyclic wave.

Several records were taken with recorder B on a suspension clamp which had a spring working in compression, connected between the clamp and the insulator string. Simultaneous records were taken on the bottom conductor, at each side of this clamp. A few tests were also taken on the middle wire and the bottom wire, at the same time, with the recorder attached to opposite sides of their respective clamps. There seemed to be a marked vibration interference on both sides of the clamp, as both of the wave forms were very irregular and broken up. When comparing the vibrations of the middle wire which was supported on a standard clamp, with the vibrations in the bottom wire hung in the special compression spring clamp, the latter generally showed less amplitude, but nothing definite can be said about this, due to the few records taken.

Conclusions

The following conclusions were reached after a close study of all the records taken, and apply only to the type of conductor, the particular location, span, and tension used. It is quite probable that the same general conditions would be found in other conductors regardless of size, tension, and span.

1. For the particular type conductor and damper tested, one damper installed on the conductor approximately 4.5 ft (1.37 m) from the suspension clamp at each end of the same span will sufficiently limit vibration under all conditions, and is better from a damping standpoint than an additional number.

2. The most prevalent frequencies are between 8 and 16 cycles per second, and hence the calculated loop lengths are between 17 ft (5.2 m) and 11 ft (3.36 m) for the conditions under which the test was made.

3. The frequency in one span is generally within one cycle of that in the adjacent span, but is rarely the same.

4. No difference was noticeable between the effect produced by the use of the trunnion and non-trunnion type of clamps on the amplitude or frequency of vibration, or the tendency to either retard or aid the transmission of vibration waves from one span to the adjacent one.

5. Uniform amplitude does not occur for periods of more than one second and the frequency often changes 1 or 2 cycles per second within a few seconds.

May Be Visited During Pacific Coast Convention

"Temple of Osiris" in Bryce Canyon, in southwestern Utah, will be visited by many of those attending the Institute's Pacific Coast convention in Salt Lake City, Sept. 3–7, 1934. Bryce Canyon is a "box" canyon filled with a countless array of fantastically erroded pinnacles, and is generally considered to be the best exhibit of vivid coloring of the earth's materials

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Of Institute and Related Activities

Plan Your Vacation to Include the Pacific Coast Convention at Salt Lake City

THE PACIFIC COAST convention this year will be held September 3–7, 1934, in Salt Lake City, Utah, which offers to many members unusual possibilities to combine a few vacation days with the convention trip. Yellowstone National Park is but a night's ride by rail from Salt Lake City. Within the boundaries of Utah and in Northern Arizona there are located such scenic wonders as the Grand Canyon, Zion, and Bryce Canyons. For those who are interested in the wonders of engineering as well as the wonders of western scenery there is a possibility of combining a trip to Boulder Dam (now at its most interesting construction stage) with the convention trip through the Utah parks. In addition the committee has arranged the schedule of technical sessions during the mornings, except on the opening day, so as to leave the afternoons free to enjoy sightseeing trips, inspection tours, or recreation in the form of golf or bathing at some one of the many delightful recreational centers within an hour's ride of Salt Lake City. Convention headquarters will be in the Hotel Utah.

Technical Program

A technical program of broad scope and current interest has been developed to appeal particularly to western engineers. A session on communication has been scheduled on Monday afternoon. On the mornings of the following days sessions will be held on the subjects of management, protective devices, lightning, transmission, and selected subjects. In addition, student sessions will be held on the afternoons of Tuesday and Wednesday, September 4 and 5, respectively.

The transmission session should have unusual appeal as it deals with some of the latest studies in stability, vibration, corona, and insulation, and some of the papers are related to the Boulder Dam transmission projects.

Entertainment Features

On Monday evening, September 3, there will be a reception in the ballroom of the Hotel Utah followed by dancing. This will be one of the most important entertainment features of the convention and it is hoped there will be a full attendance by members with their wives and guests.

On Thursday evening, September 6, following the golf tournament, the principal banquet of the convention will be held at the Salt Lake City Country Club. The awarding of the golf prizes will take place at this banquet and it will be followed by dancing.

The ladies have not been neglected in the entertainment arrangements. Sightseeing tours and social events are being planned and the details will be announced later.

Sports

On the afternoon of Thursday, September 6, there will be a golf tournament at the Salt Lake City Country Club. The John B. Fisken Cup competition, open only to members of the Pacific Coast Sections, will take place at this time. There will of course be competition for other prizes which will be open to all registered members and guests attending the convention.

Trips

On Friday afternoon, September 7, it is expected that those who intend to make a tour of the Utah National Parks and the Grand Canyon will start on their trips. The Boulder Dam inspection trip will also begin on Friday afternoon.

Technical Program

All papers are scheduled for publication in ELECTRICAL ENGINEERING prior to the convention. For the papers which already have been published reference to the issue and page is given after each title in the list which follows. The remaining papers are scheduled for publication in the August issue. Members who wish to follow the presentation in detail and discuss the papers are urged to take the necessary issues to the convention.

Monday, September 3

2:00 p.m.—Communication

TELEVISION, A. H. Brolly, Television Laboratories, Ltd.

RESONANT LINES IN RADIO CIRCUITS, F. E. Terman, Stanford University. July, p. 1,046–53

WIDE-BAND OPEN-WIRE PROGRAM SYSTEM, H. S. Hamilton, American Tel. & Tel. Co. April, p. 550–62

LINE FILTER FOR PROGRAM SYSTEM, A. W. Clement, Bell Telephone Laboratories. April, p. 562–6

Tuesday, September 4

9:00 a.m.—Management and Protective Devices

THE THEORY OF INCREMENTAL RATES AND THEIR PRACTICAL APPLICATION TO LOAD DIVISION, PARTS I AND II, M. J. Steinberg and T. H. Smith, Brooklyn Edison Co. March, p. 432–45; April, p. 571–84

JOINT USE OF POLES WITH 6,900-VOLT LINES, W. R. Bullard, Electric Bond and Share Co., and D. H. Keyes, American Tel. & Tel. Co. Dec., p. 890–8

SOME RECENT RELAY DEVELOPMENTS, Lloyd F. Hunt and A. A. Kroneberg, Southern California Edison Co., Ltd. April, p. 530–5

DISTANCE RELAY ACTION DURING OSCILLATIONS, E. H. Bancker and E. M. Hunter, General Electric Co. July, p. 1,073–80

THE EXPULSION OIL CIRCUIT BREAKER, A. C. Schwager, Pacific Electric Mfg. Corp. July, p. 1,108–15

Wednesday, September 5

9:00 a.m.—Lightning

LIGHTNING INVESTIGATION ON TRANSMISSION LINES—IV, W. W. Lewis and C. M. Foust, General Electric Co.

LIGHTNING INVESTIGATION ON 220-KV PENNSYLVANIA POWER AND LIGHT COMPANY SYSTEM 1931–1933, Edgar Bell, Pennsylvania Power & Light Co.

COUNTERPOISE TESTS AT TRAFFORD, C. L. Fortescue and F. D. Fielder, Westinghouse Electric & Mfg. Co. July, p. 1,116–23

LIGHTNING PERFORMANCE OF 132-KV LINES, Philip Sporn and I. M. Gross, American Gas & Electric Co.

FIELD TESTS ON THE COUNTERPOISE, L. V. Bewley, General Electric Co.

Thursday, September 6

9:00 a.m.—Transmission

FIELD TESTS ON CONDUCTOR VIBRATION, E. M. Wright and Joseph Mini, Jr., Pacific Gas & Elec. Co. July, p. 1,123–7

CORONA LOSSES FROM CONDUCTORS OF 1.4-INCH DIAMETER, Joseph S. Carroll, Stanford University, Bradley Cozzens, and T. M. Blakeslee, Dept. of Water and Power, City of Los Angeles, California. Dec., p. 854–60

POWER LIMITS OF 220-KV TRANSMISSION LINES, Alex. A. Kroneberg, Southern Calif. Edison Co., Ltd., Los Angeles, and Mabel Macferran, Metropolitan Water District of Southern California, Los Angeles. Nov., p. 758–66

POWER LIMITS OF SYNCHRONOUS MACHINES, Edith Clarke and R. G. Lorraine, General Electric Co. Nov., p. 780–7

THE INSULATOR STRING, R. W. Sorensen, California Institute of Technology.

PROPERTIES OF CONTAMINATED GLASS AND PORCELAIN SURFACES, W. A. Hillebrand, University of California.

Friday, September 7

9:00 a.m.—Selected Subjects

SIMPLIFIED MEASUREMENTS OF SOUND ABSORPTION, A. L. Albert and T. B. Wagner, Oregon State College.

A GLOW DISCHARGE ANEMOMETER, F. C. Lindvall, California Institute of Technology. July, p. 1,068–73

ELECTRICAL FIGURES ON PLATES IN AIR, J. Gibson Pleasants, California Institute of Technology. Feb., p. 300–7

REIGNITION OF AN ARC AT LOW PRESSURES, S. S. Mackeown, J. D. Cobine, and F. W. Bowden, California Institute of Technology. July, p. 1,081–5

INSULATOR ARCOVER IN AIR, F. W. Maxstadt, California Institute of Technology. July, p. 1,062–8

RULES ON PRESENTING AND DISCUSSING PAPERS

At some of the technical sessions, a few papers may be presented only by title. This will permit the devotion of more time to discussion. At other sessions, papers will be presented in abstract, 10 min being allowed for each paper unless otherwise arranged, or the presiding officer meets with the authors preceding the session to arrange the order of presentation and allotment of time for papers and discussion. Authors will be notified officially in each case about one month in advance.

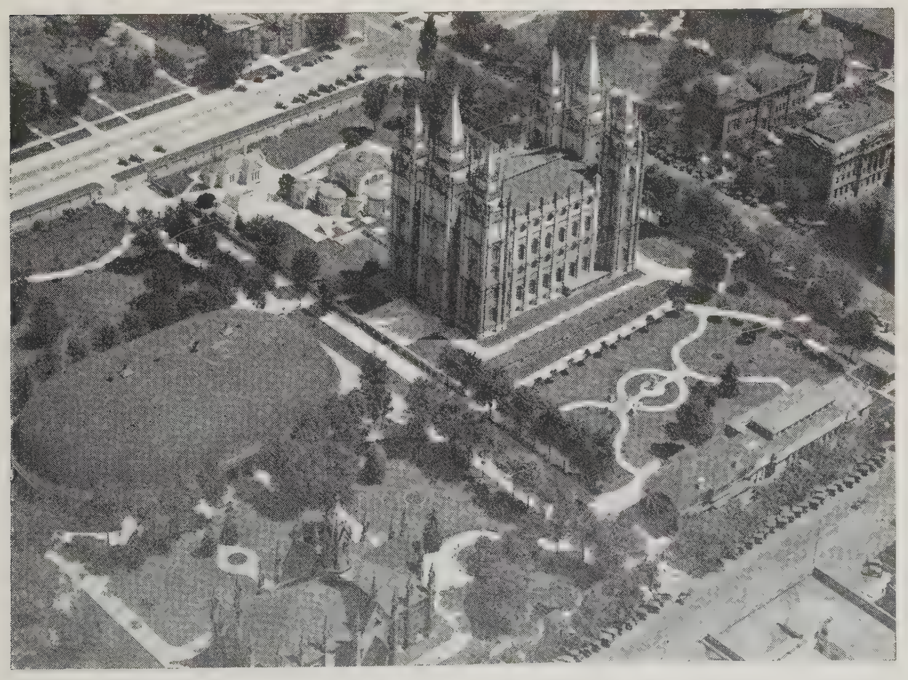
Any member is free to discuss any paper when the meeting is thrown open for general discussion. Usually 5 min are allowed to each discusser for the discussion of a single paper or of several papers on the same general subject. When a member signifies his desire to discuss several papers not dealing with the same general subject, he may be permitted to have a somewhat longer time.

It is preferable that a member who wishes to discuss a paper give his name in advance to the presiding officer of the session at which the paper is to be presented. Each discusser is to step to the front of the room and announce, so that all may hear, his name and professional affiliations. Three typewritten copies of discussion prepared in advance should be left with the presiding officer.

Other discussion to be considered for publication *must* be submitted, typed double spaced, in triplicate to C. S. Rich, secretary of the technical program committee, A.I.E.E. headquarters, 33 West 39th St., New York, N. Y., on or before Sept. 21, 1934. Discussion received after this date will not be accepted.

COMMITTEES

The general convention committee for the 1934 Pacific Coast convention consists of the following members: B. C. J. Wheatlake, *chairman;* R. W. Sorensen, *vice-chairman;* W. R. Barrett, *treasurer;* and W. M. Allen, A. P. Hill, G. L. Hoard, A. H. Hull, F. O. McMillan, H. T. Plumb, W. C. Smith, L. B. Stacey, J. A. Thaler, and V. B. Wilfley. The chairmen of the various subcommittees working with the general convention committee are as follows: technical program, A. LeRoy Taylor; finance, J. A. Kahn; transportation, C. A. Malinowski; hotels and registration, L. E. Brown; reception, C. R. Higson; entertainment, W. L. Winter; golf, J. A. Hale; publicity, L. B. Fuller; student activities, J. Hugh Hamilton; and ladies' entertainment, Mrs. L. B. Fuller.



The famous Temple Square in Salt Lake City. In the center is the temple of the Mormon Church, the large building at the left being the tabernacle. Salt Lake City, the scene of the Institute's Pacific Coast convention, Sept. 3–7, 1934, affords these and many other points of outstanding interest to visitors

Summer Convention to Be Reported in Next Issue

The 50th annual summer convention of the Institute held in Hot Springs, Va., June 25–29, 1934, with headquarters in The Homestead, was in progress as this issue went to press. A detailed report of this convention, including the annual business meeting with presentation of prizes and medal; 50th anniversary meeting; conference of officers, delegates, and members; directors' meeting; technical sessions; and inspection trips and entertainment features is scheduled for publication in the August issue of ELECTRICAL ENGINEERING.

Technical Committee Reports Postponed

The annual reports of those technical committees of the Institute which have compiled reports for the past year were stated in the June issue of ELECTRICAL ENGINEERING to be scheduled for publication in the present issue. However, publication of these annual reports has been indefinitely postponed pending recommendation of the Institute's technical program committee.

A.I.E.E. Directors Meet in New York

The regular meeting of the board of directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, N. Y., on Friday, May 25, 1934.

Present: *President*—John B. Whitehead, Baltimore, Md. *Past-president*—H. P. Charlesworth, New York, N. Y. *Vice-presidents*—J. Allen Johnson, Buffalo, N. Y.; and E. B. Meyer, Newark, N. J. *Directors*—L. W. Chubb, East Pittsburgh, Pa.; A. B. Cooper, Toronto, Ont.; A. E. Knowlton, New York, N. Y.; Everett S. Lee, Schenectady, N. Y.; L. W. W. Morrow, New York, N. Y.; A. C. Stevens, Schenectady, N. Y.; and H. R. Woodrow, Brooklyn, N. Y. *National treasurer*—W. I. Slichter, New York, N. Y. *National secretary*—H. H. Henline, New York, N. Y.

The board adopted a resolution in memory of past-president William S. Lee, who died on March 24, 1934. (The resolution appears elsewhere in this issue.)

The annual report of the president of United Engineering Trustees, Inc., was presented in person by Harold V. Coes, president, U.E.T.

Minutes were approved of a meeting of the board of directors held January 22, 1934, and of the executive committee held March 9, 1934.

Reports of meetings of the board of examiners held April 11 and May 23, 1934, were presented and approved. Upon the recommendation of the board of examiners, the following actions were taken: 2 applicants were transferred to the grade of Fellow; 6 applicants were elected and 13

were transferred to the grade of Member; 200 applicants were elected and 1 was reinstated to the grade of Associate; 242 Students were enrolled.

Future AIEE Meetings

Pacific Coast Convention,
Salt Lake City, Utah, Sept. 3–7, 1934

Winter Convention,
New York, N. Y., Jan. 22–25, 1935

South West District Meeting,
Oklahoma City, Okla., Apr. 26–28, 1935

Summer Convention,
Ithaca, N. Y., June 24–28, 1935

Pacific Coast Convention,
Los Angeles vicinity, Fall 1935

Great Lakes District Meeting,
Indianapolis—Lafayette Section territory (Date to be determined)

The finance committee reported disbursements as follows: March, $15,118.38; April, $20,510.97; May, $21,439.72. Report approved.

The national secretary reported 1,842 members in arrears for dues for the fiscal year which ended April 30, 1934. It was voted to transfer the names of these members to a "suspended" list after the distribution of the June and July issues of ELECTRICAL ENGINEERING, and to extend the time for the payment of the dues in arrears until further action by the board.

President Whitehead reported on his visits to various Sections of the Institute.

Sec. 58 of the By-Laws was canceled, thus eliminating the provision for subscription to ELECTRICAL ENGINEERING at the reduced rate of $3 per year by students who are not enrolled in the Institute. As the changes in the Institute's publication plan have nearly doubled the amount of technical material previously supplied in ELECTRICAL ENGINEERING, the expense involved seemed to make it undesirable to continue to supply the publication at $3 per year to students not enrolled in the Institute, and since the recent adoption of amendments to the By-laws extending the privileges of enrollment to students in evening courses, there seemed to be less need for the provision of Sec. 58.

Upon the recommendation of the committee on coördination of Institute activities, the following schedule of meetings for 1935 was adopted:

Winter convention, New York, January 22–25, with sessions on Tuesday, Wednesday, and Thursday, and inspection trips only on Friday.
Summer convention, Cornell University, Ithaca, N. Y., June 24–28.
Pacific Coast convention, Los Angeles vicinity, in the fall, exact location and dates to be determined later.
District meetings:
(1) Great Lakes District (No. 5), Indianapolis—Lafayette Section territory, location and dates to be determined later.
(2) South West District (No. 7), Oklahoma City, Okla., April 26–28.

Upon request of the Birmingham Section, the board authorized a change in its name to "Alabama Section" and the extension of its territory to include the entire state of Alabama.

Upon request of the New Orleans Section, its territory was increased by the addition of the part of the state of Mississippi south of the northern boundaries of the following counties: Issaouena, Sharkey, Yazoo, Madison, Leake, Neshoba, and Kemper.

The annual report of the board of directors to the membership for the fiscal year which ended April 30, 1934, as prepared by the national secretary, was approved for presentation at the annual meeting of the Institute on June 25, 1934.

The annual report of the national treasurer was presented and accepted.

Annual reports of the general standing committees (exclusive of the technical committees), abstracts of which were incorporated in the annual report of the board of directors, were received.

The report of the committee on award of Institute prizes of the awards of national prizes for papers presented during 1933 was presented and accepted. (The report was published in the June 1934 issue of ELECTRICAL ENGINEERING, p. 1026.)

The appointment of a national secretary for the administrative year beginning August 1, 1934, was made in accordance with Sec. 37 of the Constitution. National secretary H. H. Henline was reappointed.

Bancroft Gherardi was appointed a representative of the Institute upon the John Fritz Medal board of award, to fill the unexpired term, ending in October 1934, of W. S. Lee, deceased.

Report was made of an invitation to the Institute to be represented at the National Conference on Street and Highway Safety, Washington, May 23–25, and of the designation by President Whitehead of F. M. Feiker as the Institute's representative at this conference.

An invitation from the Institution of Engineers, Australia, to the officers and members of the Institute to take part in the proceedings of an engineering congress to be held in Melbourne, Australia, March 11–16, 1935, in connection with the proposed celebrations of Melbourne's Centenary, 1934–1935, was accepted, and the president was authorized to appoint the Institute's representatives.

The following resolution was adopted:

RESOLVED: That the board of directors expresses its appreciation of the excellent work of the fiftieth anniversary committee and the publication committee in commemorating the fiftieth anniversary of the Institute.

Other subjects were discussed, reference to which may be found in this or future issues of ELECTRICAL ENGINEERING.

An Address On "Human Engineering Problems"

AN ADDRESS on "Human Engineering Problems" was prepared by Dr. Michael I. Pupin (A'90, F'15, HM'28, member for life, and past-president) to be delivered on April 26, 1934, at a general meeting of the Institute's New York Section, in the auditorium of the Engineering Societies Building, New York. Doctor Pupin's talk was scheduled as an important part of this meeting, which was also a commemoration by the New York Section, of the 50th anniversary of the founding of the Institute.

This address, which in the absence of Doctor Pupin was read by Dean J. W. Barker (M'26, F'30) elicited much favorable comment. The text of Doctor Pupin's address is presented herewith:

"I wish to call your attention this evening to some of the engineering problems which are seldom discussed at the meetings of the engineering societies. I call them the 'Human Engineering Problems,' in order to distinguish them from the technical engineering problems. When I was a college student engineering education was devoted exclusively to the training of young engineers in the art of solving purely technical engineering problems. Their training in the art of solving human engineering problems was unknown. You are undoubtedly puzzled by this title: 'Human Engineering Problems.' Permit me to explain its meaning by an illustration:

"Sixty years ago when my immigrant ship landed me in New York, I took a walk on lower Broadway and saw what looked to me like a cobweb of wires stretching across the housetops of Broadway. I wondered what it meant. I was told that these wires carried electrical signals between New York and the various places in the United States. My untutored mind could not quite grasp what that meant and I made many efforts to unravel the mysteries of electrical signaling. That was the beginning of my interest in electrical communications. Two years later, that is in 1876, I saw the first telephone exhibited at the Centennial Exposition in Philadelphia. Its performance looked to me like a miracle. A month or so later I was told by a scoffer that it was a silly toy only. But in a little over half a century this toy has given us a gigantic industry which is the result of the creative work of the American engineer. Since 1876, when Bell first exhibited his great invention, the telephone industry has grown from what the scoffer considered a silly toy, to an industry capitalized at 5 billion dollars. It has been absorbing about 100 million dollars annually during the last 50 years, and one would be inclined to expect that so rapid a growth would be a mushroom growth.

"But listen to what I once heard the experts say about it. Twenty years ago a commission of 12 German engineers came over, in order to study our industrial organization. At the start of their return trip to Germany I met them here in New York and heard them speak as follows: 'Your American industries are not better organized than our German industries,

and we did not have much to learn. Your telephone industry, however, is a great exception. Nothing in Germany can approach the wonderful organization of your telephone industry.' This confession of the Germans thrilled me, and I said, jokingly: 'Your Kaiser said on a certain occasion that there are only 2 great organizations in the world. The first is the German army, and the second is the Roman Catholic Church. Tell him when you return, that the first is the American Telephone industry and nobody cares which is second.' The Germans saw the joke and said: 'We shall do so if we have a chance. But remember that at German Court receptions there are no engineers. Politicians and soldiers are the ornaments of the German Court; the engineers are never seen there, not even in the back seats.' We hope that American engineers stand higher in the social scale.

"I wonder what these German engineers will say when they hear that the great American Telephone industry which thrilled them so much is being investigated by a Federal commission consisting of politicians and that the chairman of this commission in his latest report asks the following questions:

'How much more should it cost to place a long distance call from Washington to San Francisco than from Washington to Baltimore?'

'............If 20 cents be a reasonable charge for such service from Washington to Baltimore, may it not be possible to place a call with any exchange in any American city at approximately the same cost?'

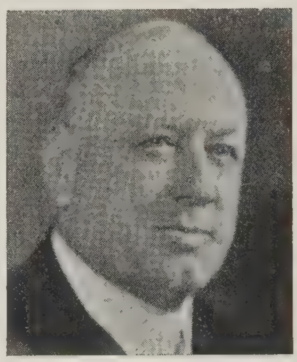
"No question ever asked displayed a more lamentable lack of expert knowledge, and it was framed by the chairman of the Federal investigating commission. A Federal investigating commission consisting of politicians who are totally ignorant of the technical arts which they are expected to investigate will certainly bring discredit upon American science and engineering. To prevent the appointment of such commissions is one of the human engineering problems of our profession.

"Just one more illustration. When 60 years ago my immigrant ship entered New York harbor my untutored peasant mind was bewildered by the sight of this great metropolis. Today, my mind, although incomparably more experienced than on that memorable day, is even more bewildered when I contemplate the great changes which American engineering has created in this marvelous town. The picture of New York of 60 years ago looks like a picture of a little village when put alongside of the picture of New York of today. Just think of its sky-high steel palaces served by speedy electrical elevators, by incandescent lighting, and by telephones which connect them with every point of the terrestrial globe; think of the many bridges, subways and tunnels which have transformed the modest Manhattan Island into greater New York, the greatest population center in the world; just think of the hundreds of millions of dollars which flow annually into the City treasury for the support of its complex administration; just think of all these things which were not even dreamed of 60 years ago and you will see clearly the great achievements of American engineering which is represented by the awe inspiring structure called Greater New York. No other civic center ever offered to man a greater opportunity for an administration of splendid engineering efficiency. And yet this wonderful home of organized American engineering is on the verge of bankruptcy. Engineers look on helplessly at the destructive work of the greedy politicians, but as a civic body they do nothing to stop the barbarous abuse of political power. It is indeed one of the greatest missions of our profession to gain for the engineer a greater share in the administration of the American cities which owe their existence to his creative work. But our profession cannot perform that mission unless it is trained in the art of solving human engineering problems."

Illuminating Engineering Society Meeting. The 28th annual meeting of the Illuminating Engineering Society is to be held in Baltimore, Md., Oct. 1–4, 1934. The convention this year offers the following outstanding features: The 10th lighting service conference—a vigorous, forceful meeting; the lighting equipment exposition—greatly expanded—a real feature; the technical and business sessions—covering a wide range of interests; and social events and inspection trips of unusual character. The many interesting things that have happened in the lighting industry and in I. E. S. circles during the past year will be reviewed at this convention.

American Transit Association to Meet. The 53rd annual convention of the American Transit Association will take place in the New Exhibition Hall of the Cleveland Public Auditorium, Cleveland, Ohio, Sept. 24–28, 1934. In connection with this convention, the operating and manufacturing members of the association will hold an exhibition of equipment, appliances, and manufactured articles of interest to executive and operating officials of the urban and interurban transportation companies.

In Memoriam



WILLIAM STATES LEE

IN THE death, on March 24, 1934, of William States Lee, the American Institute of Electrical Engineers lost its forty-third president and one of its most energetic and influential leaders.

Beginning his practical engineering career in 1897, after a brief period as instructor at the Citadel, from which he had been graduated in 1894, he rose rapidly from the positions of resident engineer of the Anderson (S. C.) Light and Power Company and the Columbus (Ga.) Power Company to become chief engineer of the latter in 1902, and vice-president and chief engineer of the Catawba Power Company, Charlotte, N. C., in 1903. In succeeding years, he served several power companies as vice-president, chief engineer, and director, the W. S. Lee Engineering Corporation as president, and the Piedmont and Northern Railway Company as president and chief engineer. He attained an enviable reputation as an executive in charge of many large power development and construction projects.

Throughout his career, his ability as an engineer, his keen perception of the controlling factors in any situation encountered, and his constant attention to the human values involved made him an outstandingly effective and a highly respected leader of men. His genial personality and wide range of information won him a multitude of friends.

Mr. Lee joined the Institute in 1904, and generously gave his time and energy to its activities in various capacities: as director 1911–14, and 1929–30, and president 1930–31; as member of a considerable number of committees, and as a representative of the Institute upon several joint organizations. He stood firmly at all times for the highest ideals of the Institute and ranked among its foremost leaders. As president of the American Engineering Council, during the years 1932 and 1933, he worked intensively and enthusiastically to make the engineering profession as helpful as possible in all problems involving engineering and affecting the public welfare.

RESOLVED: That the board of directors of the American Institute of Electrical Engineers hereby expresses, upon behalf of the membership, its deepest regret at the death of Mr. Lee and its sense of great loss sustained by the Institute and by the entire engineering profession, and be it further

RESOLVED: That these resolutions be entered in the minutes and copies be transmitted to members of his family.

—A.I.E.E. Board of Directors, May 25, 1934

Student Conference Held by North Central District

THE SEVENTH annual conference of student Branches of the A.I.E.E. in the North Central District (No. 6) was held at the South Dakota State School of Mines, Rapid City, S. Dak., April 13–14, 1934. This conference was a very successful one as indicated by both the number in attendance and the lively interest taken in all the sessions. It was a continuation of successful student conferences which have been held by this District.

Attendance

In attendance at the conference were 2 District officers: R. B. Bonney, vice president, District No. 6; and W. G. Rubel, secretary, District No. 6. Nine counselor-delegates were present, as were 9 chairmen of student Branches. In addition, 79 others were registered, bringing the total attendance to 99. The counselor-delegates present were:

J. O. Kammerman	S. Dak. State School of Mines
R. E. Nyswander	University of Denver
F. W. Norris	University of Nebraska
H. S. Rush	N. Dak. Agricultural College
H. F. Rice	University of North Dakota
W. C. DuVall	University of Colorado
C. W. Caldwell	University of South Dakota
G. H. Sechrist	University of Wyoming
W. H. Gamble	S. Dak. State College

The chairmen of student Branches who also were present as delegates were:

G. I. Welch	S. Dak. School of Mines
G. E. Bronson	University of Denver
Walker Cordner	University of Nebraska
Kenneth Brandby	N. Dak. Agricultural College
Orville T. Mundt	University of N. Dak.
Newell Parker	University of Colorado
Roy Sletvold	University of S. Dak.
George Gilleard	University of Wyoming
George Carefoot	S. Dak. State College

Friday Afternoon Session

The opening session, Friday afternoon, was called to order by Prof. J. O. Kammerman, chairman of the District committee on student activities, who introduced Dr. C. C. O'Hara, president of the South Dakota State School of Mines. Following a brief speech of welcome, R. B. Bonney took charge of the conference. In addition to the following schedule of papers and discussions which were presented, a number of lively discussions took place:

What Lies Ahead for the Engineering Graduate of Today? Prof. F. W. Norris, University of Nebraska.

Discussion, O. T. Mundt, chairman, University of North Dakota Branch.

Should Engineers Enter the Political Field? Prof. W. H. Gamble, South Dakota State College.

Discussion, K. Brandby, chairman, North Dakota Agricultural College Branch.

How Can Interest in the Student Branches Be Stimulated? Prof. H. F. Rice, University of North Dakota.

Discussion, Prof. C. W. Caldwell, University of South Dakota; George Gilleard, chairman, University of Wyoming.

New Problems Confronting Student Branches, Dr. R. E. Nyswander, Denver University.

Discussion, G. E. Brunson, chairman, University of Denver.

Banquet Held

The delegates to the conference and some 75 others were entertained at a banquet and program arranged by the student Branch of the South Dakota School of Mines and held in the ballroom of the Alex Johnson Hotel in Rapid City. G. I. Welch was toastmaster. The program follows:

Developments in Communications, T. L. Frank, head of department, building and equipment, Northwestern Bell Telephone Company, Omaha, Neb.

Motion Pictures, George Low, State School of Mines.

Introduction of Guests, Prof. J. O. Kammerman, State School of Mines.

The District Student Conference, R. B. Bonney, vice president, District No. 6, A.I.E.E.

Appreciation, Dr. C. C. O'Hara, president, State School of Mines.

Before the second session of the conference on Saturday, a number of the delegates and guests enjoyed an early morning ride to the Rushmore Memorial, about 30 miles from Rapid City, where the face of George Washington has been carved in the solid granite of Mt. Rushmore, by the famous scupltor, Gutzen Borglum.

Saturday Morning Session

The Saturday morning session was called to order by R. B. Bonney, and the following papers and discussions were presented:

Gold Mining in the Black Hills, Dr. J. P. Connolly, vice president, State School of Mines.

Report on Annual Convention of A.I.E.E. at Chicago, Prof. J. O. Kammerman, State School of Mines.

What Can Branches Do to Promote Institute Membership? Prof. G. H. Sechrist, University of Wyoming.

Discussion, N. Parker, chairman, University of Colorado Branch.

The Engineering Council for Professional Development, Prof. W. C. DuVall, University of Colorado.

Discussion, G. Carefoot, chairman, South Dakota State College Branch.

How Far Should Engineering Schools Be Held Responsible for Finding Employment for Graduates? Prof. H. S. Rush, North Dakota Agricultural College.

Discussion, W. M. Cordney, chairman, University of Nebraska.

Following this program, a resolution was unanimously adopted by the conference, congratulating the South Dakota School of Mines Branch upon its efficient management of the conference, and thanking Doctor O'Hara and Professor Kammerman for their hospitality.

Counselors' Meeting

Immediately following the Saturday morning session, a brief meeting of the student counselors was held. This was called to order by Professor Kammerman who stressed the desirability of rotating the meeting place of the student's conference. On the invitation of Professor Rush, the North Dakota Agricultural College, at Fargo, was selected for the 1935 conference. Professor Rush also was elected chairman of the District committee on student activities for the ensuing year, and was selected automatically as delegate to the Institute's 1934 summer convention.

The selection of student counselors was discussed, and the counselors were requested by the secretary to begin the consideration as early as possible of papers to be submitted during 1934 for the District prize.

Five-Year Course Added at M. I. T. A new departure in technological training to meet a growing demand for engineers with a thorough understanding of the social and economic implications of their profession was announced recently by Karl T. Compton (F'31) president of Massachusetts Institute of Technology, Cambridge, in a statement that this institution will offer a new 5-year course which will include advanced studies in the social sciences and economics. The new course, which in no way affects the regular 4-year courses in science and engineering at M. I. T., will be offered next Autumn in nearly all the professional fields of the curriculum.

Boulder Dam Power Transformers. Among the equipment recently placed on order by the federal government for Boulder Dam, Colo., are 11 power transformers, 7 of which are rated at 55,000 kva at 287,000 volts, and to be manufactured at the Pittsfield, Mass., works of the General Electric Company. Shipment of the transformers, valued at about $1,000,000, is scheduled in about a year. The larger transformers will be water cooled, will weigh over 200 tons each, and will be approximately 32 ft high, 20 ft wide, and 13 ft deep. The 4 smaller ones will be rated 13,333 kva at 138,000 volts, and will be forced-oil cooled.

Work Begins on Fort Peck Dam. Several hundred men are already engaged in the first stages of the work of building the Fort Peck Dam, the gigantic federal project on the Missouri River in Montana. This dam will be the largest earth filled barrier ever built, and will create a reservoir 175 miles long, and will cost some $72,000,000. Total length of the dam, including wings, will be nearly 4 miles. The dam will be 230 ft high, 100 ft wide at the top, and 2,658 ft thick at its base. Its purpose is to provide a 9-ft channel in the Missouri River throughout the year, aid in flood control, provide unemployment relief, and provide a site for power development. It is estimated that 4 years will be required for construction. A contract amounting to more than $500,000 has been awarded the Westinghouse Electric and Manufacturing Company for electrical substation equipment including high voltage switching equipment, 4 16,667-kva transformers, 2 20,000-kva synchronous condensers, and other equipment. Four pipe line dredges will utilize much of the power of the substation.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or to reject them entirely.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

History of Thomson-Houston Company Name

To the Editor:

"We have been reading with considerable interest the Jubilee Number of the official monthly journal and transactions of the A.I.E.E., dated May 1934. In the biographical section we were particularly interested in the notes regarding Professors Elihu Thomson and E. J. Houston.

"You are probably aware that the Thomson-Houston Company referred to therein, founded in Philadelphia in 1879, became a world wide organization; but in most countries the name has since been changed, and we believe we are right in saying that our company is the only one remaining which still bears the names of these 2 distinguished scientists."

Very truly yours,

H. A. PRICE-HUGHES
(The British Thomson-Houston Co., Ltd., Rugby, England)

Cable Failure and Dielectric Deterioration

To the Editor:

In his paper "Accelerated Aging Tests on High-Voltage Cable," appearing in ELECTRICAL ENGINEERING for June 1933, p. 371–7, D. W. Roper discusses the factors by which the quality of cables, as related to their life under service conditions, may be judged. He finds the primary criterion by which cables may be so judged to be the stability of the insulation during accelerated aging tests. That is, there should be no significant increase in power factor at maximum and minimum temperatures and no significant increase in ionization factor at room temperature (See conclusion XI, p. 376). These conclusions are in very close agreement with results obtained from accelerated life tests of cables conducted at the Harvard Engineering School.

This work was performed under the then Joint Cable Research Committee of the N.E.L.A., A.I.E.E., and A.E.I.C., of which Mr. Roper was chairman. Ten different samples in duplicate lengths from 6 different manufacturers were available for the accelerated life tests. Space permits the presentation of only a small proportion of the total results obtained. All cables were impregnated paper with $^6/_{32}$ in. (4.76 mm) wall. Nos. 18 and 19T were 300,000 cir-mil copper; Nos. 23, 25, and 25T were 600,000 cir-mil copper. Nos. 25 and 25T were the duplicate lengths from one manufacturer. The samples were prepared so that the test length of sheath was 10 ft (3.05 m); in some cases it was necessary to reduce this because of failures in the sheath cuts which are necessary to give the end guards and shielding. In 2 important respects, our methods of testing were disadvantageous in comparison with Mr. Roper's. Our samples of 10 ft (3.05 m) and less are not nearly so representative as the 25 ft (7.6 m), 50 ft (15.2 m) and 1,000 ft (305 m) samples tested by him; we had no opportunity to correlate our tests with service conditions. On the other hand, it was possible for us to make complete electrical measurements at several voltages almost daily, so that electrical changes in the dielectric were followed closely. Also, the losses were separated into the solid-dielectric power and the ionization power ("Ionization Studies in Paper-Insulated Cables, II," by C. L. Dawes, H. H. Reichard, and P. H. Humphries. TRANS. A.I.E.E., v. 48, 1929, p. 382–95).

The entire 10 samples were first submitted to accelerated life tests, at room temperature only, at 42.5 kv, corresponding to an average gradient in the dielectric of approximately 225 volts per mil. Mr. Roper, under "Dielectric Power Loss," states that initial power factor tests on insulation made at the factory indicate no significant differences that can be correlated with the rate of deterioration. We found this essentially true. However, it appeared that those cables that had initially little or no ionization loss, or which reached this condition within a few hours, as a rule showed the longer lives. For example, in Fig. 1 the ionization power is plotted as a function of the life in hours. Cable 18 showed no ionization loss until after 150 hr, and its life of 785 hr by far exceeded those of the cables showing initially or subsequently substantial ionization loss.

The tests made at room temperature showed that failure might be preceded by an increase in solid dielectric power, and more frequently by an increase in ionization power. This effect is illustrated in Fig. 1

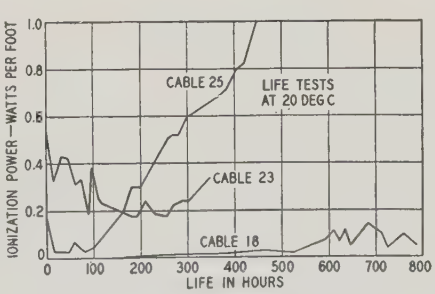


Fig. 1. Life tests at 20 deg C

which shows 3 typical ionization-power characteristics. Cable 18 showed no ionization power until after 150 hr; from 150 to 525 hr, the ionization power was very small; between 525 and 785 hr it increased in varying amounts, from 2 to 8 times its earlier values and then failed. Cables 23 and 25 had initial ionization factors of 0.43 per cent and 0.15 per cent. For some hours they both showed marked diminution in ionization power, and then rapid increase to failure.

Duplicate samples of these cables which had diverse initial characteristics were selected for accelerated life tests during which the temperature and the applied potential underwent weekly cyclic changes. The potential was varied from zero to 225 volts per mil, and the temperature from room temperature (about 20 deg C) to 60 deg C. Frequent measurements were made regularly at various temperatures during the cyclic changes, and also at various potential gradients. Although we were not able to classify our cables into low and high grades as does Mr. Roper, we found, as he did, large increase in dielectric loss sometimes varying over a wide range during the tests. This is illustrated by cable 25T in Fig. 2, which shows solid-dielectric loss per foot at 60 deg C as a function of time. We did find, however, with all the cables that survived the first few hours, a progressive increase in the solid-dielectric loss at all temperatures. The characteristic for cable 25T is given not only as an example of widely fluctuating losses, but also as an example of progressively increasing solid-dielectric loss. Cable 19T apparently was

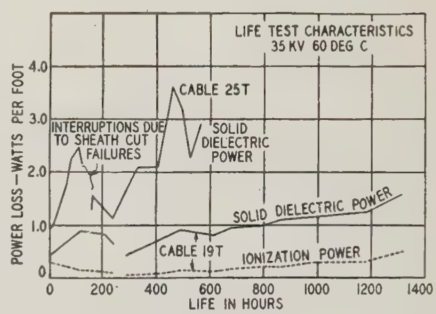


Fig. 2. Life test characteristics at 35 kv and 60 deg C

of high grade. It showed an initial ionization factor of 0.06 per cent, but a study of the ionization-power characteristic of Fig. 2 shows that this must have diminished up to 600 hr. However, this cable after 300 hr showed a progressively increasing solid dielectric loss up to the end of its life at 1,315 hr. The rate of increase of both the solid-dielectric loss and the ionization power increased as the cable approached the end of its life. All cables subjected to the cyclic temperature and voltage tests showed a progressive solid-dielectric power loss with time, whereas as a rule the increase in ionization power was not significant.

Mr. Roper mentions the rapid increase in local heating preceding failure. One of our cables failed while measurements were being made. The thermocouples on the sheath suddenly showed a rapid rise in temperature

which reached several degrees above the ambient temperature, and then failure occurred. The sheath was excessively hot over its entire length.

Mr. Roper mentions the recuperative properties of the insulation. This is illustrated in Fig. 2 for both cables, when failures in a sheath cut interrupted the life test of each cable for some hours.

It is interesting to learn that through exhaustive electrical tests it has become possible to predetermine whether or not cables can be expected to give satisfactory service performance; however, as Mr. Roper states, it is not yet possible to detect local defects before ultimate failure.

Very truly yours,

C. L. Dawes (A'12, M'15)
(Harvard University, Cambridge, Mass.)

P. H. Humphries (A'26)
(Tulane University, New Orleans, La.)

Rocking Indirect Arc Electric Furnaces

To the Editor:

In the January 1934 issue of Electrical Engineering, p. 132–8, is a very interesting article entitled "Rocking Indirect Arc Electric Furnaces" by E. L. Crosby. In reading this article several inaccuracies are apparent and we are taking the liberty of pointing these out. Our criticisms are as follows:

Deoxidizing Atmosphere

Under the heading "Deoxidizing Atmosphere" the statement is made that:

"in melting of nonferrous alloys such as brass or bronze, the indirect arc furnace ordinarily shows a net metallic loss in actual melting operation of only 10 to 25 per cent of the losses involved in the operation of fuel fired furnaces, which they have supplanted."

As the prospectus sheets of the Detroit Arc Furnace Company give metal losses as from 1 to 2 per cent on brass, the implication is that crucible furnaces show losses of from 4 to 20 per cent. This is certainly not the case and is quite a harmful exaggeration. Metal losses in crucible furnaces as taken from the article in *Metal Industry* (May, June, and July issues, 1933) which is an average cross section of a large amount of data on the subject, shows the true figure as being from 1 to 2.5 per cent, with extreme cases of 4 per cent for very high zinc brasses.

Under the same heading the statement is made:

"air may be introduced into this type of furnace under precise control, a feature that has been found valuable to many users."

It is not stated that when it has attempted to eliminate or reduce the objectionable carbon monoxide atmosphere with this expedient, electrode consumption may run as high as 12 to 15 lb per ton of metal melted, this adding materially to the melting cost.

Rocking Action

Under the heading "Rocking Action" the statement is made:

"it will be recognized immediately that this reaction (rocking) must effect improved thermal efficiency since it involves the transmission of refractory heat to the metal charge instead of through the refractory to be lost to the surrounding atmosphere. This insures lower power consumption."

It is true that such a rocking action produces a more efficient heat transfer, but to the reader it might wrongly imply sufficient efficiency to eclipse all other forms of melting—example figures in this regards may prove interesting:

At a consumption of 300 kwhr per ton of red brass the thermal input is 1,024,000 Btu as against 4,300,000 Btu to melt a ton of red brass with oil; however, with oil at 5 cents per gallon and electrical energy at 2 cents per kwhr the thermal cost per ton of metal melted for the oil fired crucible furnace is $1.50 versus $6.00 for the power for indirect arc furnaces.

From a metal qualitative standpoint, much objection may be raised to the generation of all the heat for melting from an arc as all the heat is liberated in a very constricted space at a temperature of plus or minus 6,000 deg F. This is not particularly harmful in the case of melting ferrous metals, but in the case of brasses and bronzes containing large percentages of low-boiling-point metals, a decided "burnt" condition may develop, which will result in a metal quality decidedly inferior for many types of foundry work.

Utilization

Under the heading of "Utilization" it is pointed out that this type of furnace enjoys very wide usage, which is quite true, but it is a fact that a large number of these furnaces have been abandoned in the brass and bronze field as per reasons given above. Valuable utilization information might be given your readers by pointing out that articles published in trade journals by the makers of this furnace acknowledge that melting costs for red and yellow brass run over $17 per ton, whereas crucible melting costs seldom exceed $10 per ton, and average under $8.

We again wish to point out that the article we are criticizing can be of considerable value to the electric power salesmen only if it does not try to encompass too many possibilities, and it is in the spirit of attempting to assist the future possibilities of electric power, as well as ourselves, that we place this information in the form of a criticism before you.

Very truly yours,

K. E. Buck
(Chairman, Technical Service Committee, Plumbago Crucible Assn., Philadelphia, Pa.)

To the Editor:

This letter is in reply to that by Mr. Buck of the Ross-Tacony Crucible Company representing the Plumbago Crucible Association, which was a criticism of the article by E. L. Crosby, on "Rocking Indirect Arc Electric Furnaces" appearing in the January 1934 issue of Electrical Engineering. Mr. Crosby was fatally injured in an automobile accident near Ludlow, Mass., on May 5, and it becomes my duty to answer the criticisms brought forth in this letter.

In presenting our answer we should like to do so with the utmost candor and friendliness but at the same time we wish to point out that many of Mr. Buck's statements are so far from accurate that our answer must necessarily be firm.

Metal Losses

Mr. Crosby's statement regarding metal losses was substantially correct as can be borne out by ample data available on comparative tests. The net metal losses when melting brass mixtures in Detroit Furnaces range from 0.25 per cent to 1 per cent depending upon composition, while the losses run from 2 per cent to 7 per cent in fuel fired furnaces depending upon furnace types and metal composition. We have demonstrated many times, the ability of this furnace to melt red brass in regular production with a net metallic loss of less than 0.5 per cent. We have scores of reports on comprehensive tests, made by many of our customers, showing from 0.25 per cent to 0.40 per cent metal loss. This fact has been thoroughly established over the past 15 years to the point that Mr. Crosby's statement is thoroughly justified.

Deoxidizing Atmosphere

Mr. Buck makes the erroneous assumption that the carbon monoxide atmosphere is objectionable for brass melting and that this is the reason for using air in the furnace at times. Many of the most competent brass foundry metallurgists would take hearty issue with Mr. Buck on this point. Furthermore, Mr. Crosby referred to the multiple uses of rocking electric furnaces in melting brass, bronze, cast iron, alloy steels, special alloys, and special chemical applications. In some cases it is desirable to introduce air for specific purposes and this can readily be accomplished in this furnace. Mr. Buck is further in error when he infers an electrode consumption of 12 to 15 lb per ton of brass melted. The use of air does increase the normal electrode consumption a definite amount depending upon the control established; but the highest figure that has come to our attention has been approximately half that mentioned by Mr. Buck. This was on a small furnace; on larger units the figure is still lower.

For Mr. Buck's information the conditions under which air is used in the furnace embody requirements which could not be met in crucible melting without a similar oxidizing treatment and we fail to see how, for the many specific applications we have in mind, this could be accomplished satisfactorily melting a stationary bath of metal in a crucible.

Rocking Action

I am unable clearly to follow Mr. Buck's line of reasoning in this regard. Mr. Crosby said exactly what he meant and he was correct in his statement. He intended making no hidden implications.

As to Mr. Buck's heat comparison on a British thermal unit basis, we fail to see the significance of this comparison. Looking

into his cost figures we find that he has quoted exceedingly low fuel cost figures—30 gallons of oil per ton of metal—approximately half the fuel consumption of many concerns with whom we are acquainted. On the other hand, the power cost quoted is somewhat high. Many concerns average substantially less than 300 kwhr per ton and less than the 2 cent figure quoted. This rate in Detroit, for example, is 1.2 cents per kilowatthour.

In objecting to the method of heat generation in the arc furnace, Mr. Buck overlooks the very basic design of the furnace, i. e., that the furnace is automatically rocked thus stirring the metal, effecting rapid and uniform heat distribution through the bath and thus avoiding the condition which he cites. In short, we feel that Mr. Buck was thinking back some years in terms of the Stassano or Rennerfelt or other stationary arc furnaces. Certainly there have been too many millions of pounds of metal melted in more than 400 installations of Detroit Rocking Electric Furnaces over the past 16 years and poured into castings of the highest quality to permit of any academic discussion regarding the feasibility of a method of melting which has been so thoroughly established and adopted by leaders of the industry.

Mr. Buck's cost figures should also be reversed or greatly modified. Many users of Detroit Electric Furnaces including the largest production foundries in their respective industries as well as many smaller jobbing shops are obtaining lower costs and better quality than from the fuel fired furnaces which they replaced. These economies accrue principally through

1. Lower metal losses
2. Lower labor costs
3. More efficient utilization of plant space
4. Frequent use of cheaper raw materials
5. The production of a higher percentage of finished perfect castings

Very truly yours,

A. E. Rhoads
(Vice president, Detroit Electric Furnace Company, Detroit, Mich.)

Standards

Report on Definitions in Electronics Field

While the Sectional Committee on Electrical Definitions has been actively at work since 1929, not until well along in 1933 was it deemed necessary to appoint a new subcommittee to cover the field of "electronics." This subcommittee was organized under the chairmanship of W. Wilson, of the Bell Telephone Laboratories, Inc.

In the official action creating the committee it was pointed out that literature in the electronics field is becoming somewhat muddled due to the fact that there is no standardization of nomenclature. In some cases several names (including trade names) are used to describe the same tube. It was therefore suggested that the subcommittee on electronics not only attempt the standardization of tube names, but suggest any other standardization of names and term definitions that seemed to them desirable.

The first report of this committee is now being issued in mimeographed form under a 60-day limit for comments and criticisms. It contains only that material upon which general agreement seemed to be obtainable without further delay. Other material may be added later. Only a limited number of copies of this preliminary report on "Electronics" is available. If particularly interested write H. E. Farrer, secretary, Sectional Committee on Electrical Definitions, A.I.E.E., 33 West 39th Street, New York, N.Y.

Standard Letter Symbols Under Revision

In February 1929 "Standard Letter Symbols for Electrical Quantities" was approved as American Standard by the A.S.A. This standard is now under revision. It is expected that additional symbols, for which there has been a call, will be added. At the same time there will be an additional column added to the listing of the quantities giving the names of the units.

Electrical Installations on Shipboard

A movement has recently developed abroad which may lead to an attempt to develop international rules for electrical installations on ships. The American Standards Association headquarters has been approached by General Secretary LeMaistre, of the International Electrotechnical Commission, as to the attitude of this country with regard to such an undertaking. A.S.A. referred the inquiry to the A.I.E.E. and it has been discussed both by the technical committee on applications to marine work and the standards committee. At the meeting of the latter committee on May 24, and following a report from the technical committee, an action was taken advising A.S.A. that in the opinion of the standards committee, if the work of international standardization of such rules is undertaken it should be under the auspices of the I.E.C. The Institute would be glad to offer A.I.E.E. Standard No. 45 "Recommended Practice for Electrical Installations on Shipboard" to the I.E.C. as a basis for the work. Incidentally, A.I.E.E Standard No. 45, which was developed under the auspices of the technical committee on applications to marine work is generally accepted by all the marine interests in the country, such as steamship owners, naval architects, shipbuilders, and classification and insurance associations.

Standards for Capacitors

In May 1930 the Institute issued in report form a proposed "Standard for Capacitors." This was offered to A.S.A. for approval as American Standard and on March 5, 1934, it was so approved. It is now available in pamphlet form as No. 18 in the A.I.E.E. series. Single copies can be obtained at a cost of 20 cents each, usual 50 per cent discount to A.I.E.E. members. Write H. E. Farrer, secretary, A.I.E.E. standards committee, 33 West 39th St., New York, N. Y.

Mercury Arc Rectifiers

The Sectional Committee on Mercury Arc Rectifiers in the fall of 1933 submitted a report on "Standards for Acceptance Tests of Metal Tank Mercury Arc Rectifiers." This report was approved by the Institute as sponsor in October 1933 for transmittal to A.S.A. with the understanding that the A.I.E.E. stood ready to issue it either as a report on a proposed standard or as an accepted standard in accordance with the decision of the electrical standards committee. This report came before the committee on scope and it was decided, because of the rapid changes taking place in the development of mercury arc rectifiers, to recommend that the work of the Sectional Committee be issued as a report. The report is now available in pamphlet form as A.I.E.E. Report No. 6. Copies may be obtained without charge by writing H. E. Farrer, secretary, A.I.E.E. standards committee, 33 West 39th St., New York, N. Y.

Noise Measurement Standards Developed

The work of the Sectional Committee on Acoustical Measurements and Terminology is rapidly taking form. The reports on nomenclature and on methods of measuring noise are now ready for letter ballot in the American Standards Association. The sectional committee is working under the sponsorship of the Acoustical Society of America and the chairman is Prof. V. O. Knudson, of the University of California. It was organized in January 1932, and since then 4 subcommittees have been actively working on the following subjects: Noise measurement; acoustical terminology; sound absorption and insulation; fundamental acoustical measurements. More complete details can be obtained from an article in the May 1934 issue of *Industrial Standardization* issued monthly by A.S.A.

Power Switchgear

The scope of the sectional committee on Power Switchgear (C37) has been extended to include a variety of apparatus in the general field of switchgear which was not included in the former scope. The work formerly covered included only oil circuit breakers, large air circuit breakers, disconnecting and horn-gap switches.

The new work includes high voltage fuses (above 750 volts) and the current limiting

resistors used with such fuses, metal-clad switchgear, relays directly associated with power switchgear, network protectors, switchgear assemblies including automatic switchgear, and power connectors of the type used with switchgear.

Engineering Foundation

Personnel Research Federation

In 1921 The Engineering Foundation and National Research Council jointly established the Personnel Research Federation. This organization has gained wide respect, but the slowness of comprehension by business executives of their human-relations problems, and the condition of business in general the last few years, have hindered the development of its usefulness. Now, the new conditions affecting intimate human relationships in industry and commerce are reaffirming the need for the kinds of service in which the Federation has been developing methods, inspiring research, demonstrating practical applications, and accumulating experience for 12 years.

A new president, C. G. Stoll, vice-president of the Western Electric Company, was elected in April 1934. Under his leadership steps already are being taken to strengthen the Federation for its large present opportunity.

The Federation, which has offices in the Engineering Societies Building, 33 West 39th Street, New York, N. Y., publishes the *Personnel Journal*, has a useful special reference library for members, and holds noteworthy meetings. It is believed that many engineers may find opportunities for new or enlarged services by making themselves competent to advise the clients in the human-relations field. Membership in Personal Research Federation should aid them in acquiring this knowledge.

New Secretary Elected by U.E.T.

The board of trustees of United Engineering Trustees, Inc., at its meeting of May 25, 1934, elected John Arms to be secretary to succeed Dr. Alfred D. Flinn, whose resignation was accepted at the same meeting. Doctor Flinn continues as director and secretary of The Engineering Foundation.

Mr. Arms has been general manager of United Engineering Trustees since December 9, 1933, and will continue to hold this office in addition to that of secretary. He is now the chief administrative officer for the board of trustees in caring for the Engineering Societies Building, Engineering Societies Library, and endowment funds which are held for the American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, The American Society of Mechanical Engineers, and the American Institute of Electrical Engineers, jointly.

Mr. Arms is a member of the industrial engineering firm of Arms and Madeheim, and is a member of The American Society of Mechanical Engineers, Cornell Society of Engineers, Society of American Military Engineers, Army Ordnance Association, and The Engineers' Club of New York. He was born at Williamsport, Pa., in 1888, and now resides in East Orange, N. J. He served in the U.S. War Department, Selective Service Division, 1918.

American Engineering Council

Engineering Affairs at Washington

National projects of interest to engineers continue to follow each other with bewildering rapidity at Washington. During the last month engineers have been related to at least one field with which they have not been officially associated, namely, the Home Owners' Loan Corporation. This organization administers the distribution of some $200,000,000 to be used for modernizing and reconditioning homes. A group of 12 regional supervisors has been established, each in charge of men with background of architectural or engineering experience. Col. Paul Doty (A'04, M'12), president of The American Society of Mechanical Engineers, was appointed regional supervisor for the states of Alabama, Florida, Georgia, North Carolina, and South Carolina. Colonel Doty's headquarters will be at Atlanta, Ga. Under the regional supervisors, state organizations have been established for considering the equities involved in the applications for this remodeling development.

It is quite probable also that the broad program of housing, the details of which have not yet been made public, will bring opportunities for engineers and engineering in the follow through of the plans. This particular operation is under the general direction of Harry L. Hopkins, Federal Emergency Relief Administrator.

Secretaries of Engineering Societies Visit Washington

On Monday, June 4, 1934, at the invitation of F. M. Feiker, executive secretary of American Engineering Council, the secretaries of several national engineering societies spent the day in Washington, D. C., contacting the government department which had the most direct relations to engineers and engineering developments. George T. Seabury, American Society of Civil Engineers; A. B. Parsons, American Institute of Mining and Metallurgical Engineers; C. W. Rice and C. E. Davies, The American Society of Mechanical Engineers; and H. H. Henline, American Institute of Electrical Engineers, were present.

During the day there were visited in order, the Department of Labor, the Department of Interior, the N.R.A., the Russian Embassy, and the Department of Commerce. In addition, John Frey, vice-president of the American Federation of Labor, and member of the labor advisory board of the N.R.A., met with the secretaries; at the luncheon meeting, the Honorable Frederick A. Delano, chairman of the National Planning Board and Mr. Charles Eliot II, executive officer of the National Planning Board, were present; at dinner the presidents and secretaries of the local sections of the respective engineering organizations were in attendance. At the various meetings and in the departments of the government which were visited, individuals in authority and well acquainted with many phases of governmental activity, contributed valuable information to the secretaries. The day's visits with the administration officials were closed with a half hour's conference with Daniel C. Roper, secretary of commerce.

Many specific suggestions for the active utilization of engineering ability in the affairs of the government and of stimulating coöperation among engineers, were introduced.

Engineers Active at Meeting of U.S. Chamber of Commerce

At the recent annual meeting of the U.S. Chamber of Commerce, Harrison P. Eddy, president of the American Society of Civil Engineers, presented a paper entitled "An Engineering Analysis of the Public Works' Program" at the round table conference on problems and progress in regional and city planning. Several other men, prominent in engineering circles, participated in the program, and at the annual dinner, the engineers were recognized professionally in the persons of J. F. Coleman, president of American Engineering Council, and by Mr. Eddy. This is considered further evidence of the increasing public recognition of the engineer in relation to national policy and national development.

Referendum on Public Works Expenditures

During May 1934, at the request of J. F. Coleman, president of American Engineering Council, and as the result of a mail vote by the executive committee, 2 questions were submitted to Council concerning the policy of Council in regard to public works. The questions are as follows:

1. Do you approve of Council actively supporting in any legitimate way the various proposals to extend credit for the development of private construction enterprise based upon the requirement of adequate security?

Yes	31
No	2

2. Shall Council support a movement to obtain additional P.W.A. Funds?

Yes	20
No	13

Personal Items

K. S. WYATT (A'32) research engineer, Detroit Edison Co., Detroit, Mich., with his co-authors E. W. SPRING (A'26, M'32) and C. H. Fellows, has been awarded the 1933 A.I.E.E. national prize for initial paper for the contribution "A New Method of Investigating Cable Deterioration and Its Application to Service Aged Cable." Mr. Wyatt was born in Cambridge, Mass., in 1900. He first studied engineering at Mount Allison University, Sackville, New Brunswick. After completing the unified 2-year course, he majored in physical chemistry, obtaining the degree of B.A. in 1921 and the degree of B.Sc. with honors in chemistry in 1922, and was an instructor in physics in 1921. After a year of graduate work in physical chemistry at Harvard University he joined the Carborundum Company, Niagara Falls, N. Y., as assistant research chemist. In the fall of 1923 he accepted a scholarship from the National Research Council of Canada, and attended the University of Toronto, where he was engaged in research on "Supersaturation of Gases in Liquids." Mr. Wyatt joined the research department of the Detroit Edison Company in 1928, and has specialized in the study of the deterioration of high voltage insulation. Mr. Wyatt is a member of the Edison medal committee of the Institute, and is also a member of the American Chemical Society; he has prepared several papers for technical publications.

E. W. SPRING (A'26, M'32) research engineer, Detroit Edison Co., Detroit, Mich., with his co-authors K. S. WYATT (A'32) and C. H. Fellows, has been awarded the 1933 A.I.E.E. national prize for initial paper for the contribution "A New Method of Investigating Cable Deterioration and Its Application to Service Aged Cable." Mr. Spring was born in New Haven, Conn., in 1903. He graduated from the Sheffield Scientific School, Yale University, in 1924 with the degree of B.S. in E.E. He then entered the operating department of the Detroit Edison Company, and in 1929 joined the research department staff, taking charge of the electrical division of the research laboratory, where he has been particularly concerned with underground cable.

F. H. GULLIKSEN (A'29) an electrical engineer for the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been awarded the 1933 A.I.E.E. national prize for best paper in engineering practice. The title of his prize winning paper is "The Principle of Condenser Discharge Applied to Central Station Control Problems." He was born in Oslo, Norway, in 1901. In 1924 he graduated from the Norwegian Institute of Technology at Trondhjem, Norway, having worked for the hydroelectric commission of Norway during summers. He was employed at Elektrisk Bureau, Oslo, during 1925 as designer of radio and telephone apparatus. In December of that year he came to the United States and entered the graduate student course of the Westinghouse company, and in 1927 entered the regulator section of the supply engineering department. Since 1928 he has been in the regulator section of the control engineering department, engaged in the development and design of electronic regulators and industrial control equipment. A recent paper by Mr. Gulliksen, "Electronic Regulator for A-C Generators," is given on p. 877 of the June 1934 issue of ELECTRICAL ENGINEERING.

J. ALLEN JOHNSON (A'07, F'27, and vice president) chief electrical engineer of the Buffalo, Niagara and Eastern Power Corporation, Buffalo, N. Y., has received honorable mention in the 1933 A.I.E.E. national prize awards for his paper in engineering practice, "Operating Aspects of Reactive Power." Mr. Johnson has been engaged in power generation work since his graduation from Worcester Polytechnic Institute in 1905, and was responsible for many important features of the electrical design of the Niagara developments following 1918. He was appointed to his present position in 1929. Mr. Johnson is president-elect of the Institute, and a more complete biography is given on p. 230 of the January 1934 issue of ELECTRICAL ENGINEERING.

W. R. SMITH (M'18, F'30) assistant chief engineer, United Engineers and Constructors, Inc., Newark, N. J., has been elected chairman of the New York Section of the Institute.

W. S. GORSUCH (A'07, M'17) engineer of economics, Interborough Rapid Transit Company, New York, N. Y., has been elected secretary-treasurer of the New York Section of the Institute.

R. H. HUGHES (A'20, M'30) assistant vice president, New York Telephone Company, New York, N. Y., has been elected to membership on the executive committee of the New York Section of the Institute.

J. A. SCOTT (A'25) electrical engineer, General Electric Company, Schenectady, N. Y., represents the Institute on the new sectional committee on electrical insulating materials of the A.S.A.

GABRIEL KRON (A'30) is now with the General Electric Company at Schenectady, in the engineering general department. He was formerly consulting engineer for the United Research Corporation, Long Island City, N. Y.

D. T. MAY (M'28) materials engineer, Bell Telephone Laboratories, Inc., New York, N. Y., represents the telephone group of the A.S.A. on its new sectional committee on electrical insulating materials.

D. L. SMITH (M'27) electrical engineer, Chicago Rapid Transit Company, Chicago, Ill., represents the American Transit Association on the new sectional committee on electric insulating materials of the A.S.A.

H. L. CURTIS (A'21, F'26) principal physicist, U.S. Bureau of Standards, Washington, D. C., was elected chairman of the new sectional committee on electric insulating materials of the A.S.A., and represents the Bureau of Standards.

R. J. COE (A'30) has been appointed assistant electrical engineer of the New England Power Association, Boston, Mass.

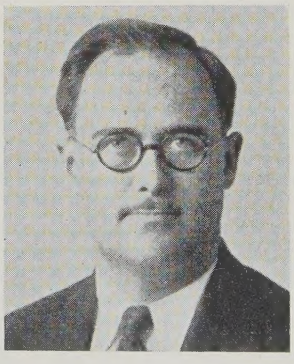
A. L. MAILLARD (M'23) has been appointed head of the new air-conditioning department of the Kansas City Power and Light Company, Kansas City, Mo.

W. R. G. BAKER (A'19) has recently been appointed vice president and general manager of the RCA-Victor Company, Harrison, N. J.

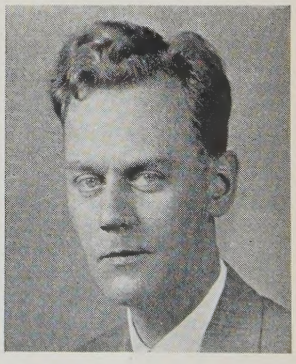
R. H. DEARBORN (A'07, F'30) formerly head of the electrical engineering department of Oregon State College at Corvallis, has been appointed acting dean of the school of engineering.

K. S. WYATT

E. W. SPRING



F. H. GULLIKSEN



W. W. LACKIE (F'16) will retire from the British Electricity Commission, London, England, in July 1934.

G. H. DUNSTAN (A'28) has been promoted from the position of instructor to assistant professor of general engineering at the University of Southern California, Los Angeles, Calif.

A. M. CHITTY (M'22) has been appointed western district manager at Bremerton, Wash., for the Puget Sound Power and Light Company. He was formerly manager of the company's southwestern district.

G. H. BUCHER (M'24) has been elected president of the Westinghouse Electric International Company and will continue in his duties as general manager. Since 1932 he had been vice president of the company.

Obituary

PAUL SUSSAN (A'24) designer and draftsman for the New York Edison Company, died on April 17, 1934, in New York, N. Y. He was born in Riga, Latvia, April 8, 1880, and attended the Realgymnasium, Mitau, Russia, the University of Bern, Switzerland, and the Polytechnicum Cöthen, Germany, receiving the electrical engineering degree from the last named in 1903. He was assistant engineer in industrial installation work for Fischer and Company of Berlin from 1903 to 1904. From 1905 to 1917 he was engaged in designing of electrical apparatus for the General Electric Company at the Schenectady and Pittsfield works. From 1917 to 1920 he was employed by the Interborough Rapid Transit Company of New York City as draftsman, checker, and squad leader. From 1920 on he worked for the New York Edison company, preparing drawings and wiring diagrams for power houses and substations. In 1924 he was graduated from the Columbia University School of Optometry with the degree of doctor of optometry, and he practiced optometry for some years.

MURRAY J. IDAIL (A'19, M'24) manager of the engineering department of the Virginia Public Service Company at Charlottesville, Va., since 1929, died on March 10, 1934. He was born March 18, 1897, at Baltimore, Md., and was educated in the public schools there, and at the Preparatory School at Old Point Comfort, Va., and the Catholic University of America, Washington, D. C., receiving the B.S. degree in electrical engineering from the university in 1917. From 1914 to 1915 he took a student course in the gas and central stations departments of the Newport News and Hampton Railway, Gas and Electric Company at Hampton, Va. From 1918 to 1919 he was in charge of electrical design of all the Navy Department work which was assigned to Mr. F. R. Weller, consulting engineer. He did important work in designing power stations, heating plants, fuel oil plants and distribution systems for the navy yards at New Orleans, Norfolk, Philadelphia, New London, and Portsmouth. From 1919 to 1924 he was engineer in charge of the electrical department of Mr. Weller's concern. This work entailed designing and installing central stations, outdoor substations, transmission lines, etc. In 1924 he had charge of the design and construction of the first step of a 125-mile 110,000-volt tower line, with substations.

GRENVILLE A. HARRIS (A'01) export manager, engineer, for Black Clawson Company, New York, N. Y., died January 31, 1934. He was born at Elizabeth, N. J., December 24, 1878. He attended Hackettstown Institute, Hackettstown, N. J., and Stevens Institute of Technology, receiving the M.E. degree from the latter. After taking the student course of the Westinghouse Electric and Manufacturing Company at Pittsburgh, Pa., he became construction engineer for the company and had charge of the erection of a number of important plants. From 1901 to 1916 he was resident engineer in charge of the electrical and mechanical work of Takata and Company, agents of the Westinghouse organization for Japan. From 1916 to 1921 he was chief engineer for the American Steel Export Company, having charge of the construction of steel plants. In 1921 he became export manager engineer, for Black Clawson Company, holding that position at the time of his death. During the Spanish-American War he was electrician, second class, on the U. S. S. Vixen, and he was awarded a war Medal for his services during the engagement of July 3, 1898. He was a member of The American Society of Mechanical Engineers.

SHIZUO KATO (A'08) president of The Institute of Electrical and Mechanical Technology, Nishikicho, Nichome, Kanda, Japan, died recently according to word received at Institute headquarters from Michihiko Hatori (A'18), director of the Japanese institution. Mr. Kato was born November 8, 1880 at Tokyo, Japan, and was graduated from the electrical engineering department of the college of engineering of Tokyo Imperial University in 1904. After leaving college he became electrical engineer engaged in designing with the Nitsubishi Dockyard and Engine Works, manufacturers of electrical machinery, at Kobe, remaining with that firm for 11 years. In 1915 he became associated with The Institute of Electrical and Mechanical Technology, acting as editor, principal, director, trustee, and president.

MARION BROWN LINES (A'31) engineer's assistant for The Mountain States Telephone and Telegraph Company, Colorado division, died April 9, 1934, in Denver, from injuries received in an automobile accident April 4. He was born at Neodesha, Kansas, January 26, 1902. In 1923 he graduated from the University of Kansas with a degree in mechanical engineering. In 1924 he began his work with The Mountain States Telephone and Telegraph Company in Colorado Springs in the construction and installation fields. In 1928 he was an assistant to the transmission and protection engineer for Colorado, becoming transmission engineer for The Mountain States Telephone and Telegraph Company in 1930. He was a first lieutenant of engineers of the Organized Reserves.

MINOR MEEK DAVIS (A'86, M'93, F'12, member for life) electrical engineer with the Postal Telegraph-Cable Company, New York, N. Y., for about 24 years, died on April 13, 1934. He was born March 28, 1858, at North Chatham, Mass., and attended the Coffin School at Nantucket, Mass. After a few years in the electrical departments of the Bankers and Merchants and United Lines companies, he entered the employ of the Postal Telegraph-Cable Company as assistant electrical engineer, becoming electrical engineer in 1907 and holding that position until 1920. He became a consulting engineer in 1920, retiring in 1925 at the age of 67.

OTTO TOMAS GIERISCH (A'07) draftsman, died a few months ago, according to word received recently at Institute headquarters from his brother. He was born on August 13, 1882, in New York, N. Y., and was educated at Stevens Institute of Technology and at Brooklyn Polytechnic Institute. He was draftsman for a short time with the Safety Car Heating and Lighting Company, and draftsman with the Brooklyn Rapid Transit Company for a number of years following 1906.

Membership

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before July 31, 1934, or Sept. 31, 1934, if the applicant resides outside of the United States or Canada.

Allan, L. F., City Hall, Toronto, 2, Can.
Barlow, P. McG., Hygrade Sylvania Corp., Emporium, Pa.
Bianchi, F., N. Y. Tel. Co., N. Y. City.
Bowen, A. E., Bell Tel. Lab., N. Y. City.
Byrd, E. C., N. Y. Edison Co., N. Y. City.
Caughman, C. D., Federal Bank, Columbia, S. C.
Clare, C. P. (Member), Associated Elec. Lab. Inc., Chicago, Ill.
Daeley, R. L., Streamstown, Alberta, Can.
Dunn, J., Waite & Bartlett X-Ray Co., Cleveland, Ohio.
Dye, J. R., Phila. Elec. Co., Pa.
Edwards, L. L., R. & H. Chemical Co., Niagara Falls, N. Y.
Eggert, W. C., Public Utilities Commission, San Francisco, Calif.
Ekstrom, E. J., Hygrade Sylvania Corp., Clifton, N. J.
Evans, M. F., Wright-Hargreaves Mines, Kirkland Lake, Ont., Can.
Fleming, J. R., Univ. of Tennessee, Knoxville, Tenn.
Goldie, M. McL., 218 McDowall Bldg., Seattle, Wash.

Halloran, J. J., U. S. Engr. Office, Havre, Mont.
Hammond, E. H., Route 1, Box 530 National City, Calif.
Harvey, O. J., Milwaukee Elec. Railway & Light Co., Wis.
Howse, S. E., Westinghouse X-Ray Co., Los Angeles, Calif.
Kopf, F. J., N. Y. Edison Co., N. Y. City.
Kuder, A. S., Wash. Water Power Co., Spokane, Wash.
Latta, A., Stanton Operating Co., Pittston, Pa.
Lindberg, C. A., United Elec. Mfg. Co., Adrian, Mich.
Lomax, C. E. (Member), Associated Elec. Lab. Inc., Chicago, Ill.
Lynch, M. E., Bureau of Standards, Washington, D. C.
Mahoney, H. P. (Member), Associated Elec. Lab. Inc., Chicago, Ill.
McMains, T. F., Western Union Tel. Co., Wichita Falls, Texas.
Nelson, M. L. (Member), Associated Elec. Lab. Inc., Chicago, Ill.
Newell, N. A. (Member), Bell Tel. Lab., N. Y. City.
Nunez, J. M., Hart Enterprise Elec. Co. Inc., New Orleans, La.
Patterson, R. T. L., Bell Tel. Lab. Inc., N. Y. City.
Pratt, M. H. (Member), Niagara Hudson System, Syracuse, N. Y.
Richards, E. L. (Member), Coyne Elec. School, Chicago, Ill.
Richards, L. J., East Bay Municipal Utility Dist., Oakland, Calif.
Salvesen, S. R., N. Y. Hospital, N. Y. City.
Stallings, C. F., Amer. Tel. & Tel. Co., Atlanta, Ga.
Stinchfield, J. M., RCA Radiotron Co. Inc., Harrison, N. J.
Takahashi, Y., 62 W. 124th St., N. Y. City.
Tsagos, H. N., 34 West 128 St., N. Y. City.
Walker, J. E. L., 62 Stibbard Ave., Toronto, 12, Ont., Can.,
Westhead, F. J., Gen. Elec. X-Ray Corp., N. Y. City.
Williams, A. D., General Cable Corp., San Francisco, Calif.
Willick, F. L., 195 N. Vidal St., Sarnia, Ont., Can.
Zaroodny, S. J., 1984 Yale Station, New Haven, Conn.

45 Domestic

Foreign

Dey, R. B., Siemens Schuckert Werke, A. G., Berlin, Germany.
El-Koshairy, M. A. B., Metropolitan Vickers Elec. Co. Ltd., Manchester 17, England.
Grobler, P. S., P. O. Box 16, Rustenburg, South Africa.
Krishnaswami, P. M. (Member), Andhra Engg. Co. Ltd., Vizagapatam, South India.

4 Foreign

Recommended for Transfer

The board of examiners, at its meeting of June 20, 1934, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Member

Althouse, Ernest E., div. operating supt., Central Hudson Gas & Elec. Corp., Kingston, N. Y.
Bardewyck, Arthur H., transm. and distr. engr., Cia. Interprovincial de Servicios Publicos, Buenos Aires, Arg., So. Am.
Bell, Delamar T., member of tech. staff, Bell Tel. Labs., Inc., N. Y. City.
Cannon, Wm. D., E.E., Western Union Tel. Co., N. Y. City.
Church, Oliver A., dist. mgr., Niagara Lockport & Ontario Pwr. Co., Batavia, N. Y.
Cramer, Clifford H., engr., Western Union Tel. Co., N. Y. City.
Faigle, Charles A., distribution engr., Central Hudson Gas & Elec. Corp., Poughkeepsie, N. Y.
Fishman, Solomon, asst. prof. of industrial engg., Newark Col. of Engg., Newark, N. J.
Fisk, Walter B., Jr., asst. inside plant engr., Bklyn. Edison Co. Inc., Bklyn., N. Y.
Foss, H. Marcus, asst. engr. of equipment, Bell Tel. Co. of Pa., Pittsburgh.
Knapp, Floyd H., field engr., Bell Tel. Labs., Inc., New York.
Ku, Yu-Hsiu, dean of engg. college, National Tsing Hua University, Peiping, China.
Moffitt, Lamont E., asst. supt. of distribution, Bklyn. Edison Co., Bklyn., N. Y.
Poole, Robert E., member of technical staff, Bell Tel. Labs., Inc., New York City.
Salsbury, Raymond J., supt. of substation operation, Duquesne Light Co., Pittsburgh, Pa.
Sanford, Frank E., distribution engr., Union Gas & Elec. Co., Cincinnati, Ohio.
Skilling, Hugh H., instructor in elec. engg., Stanford University, Calif.
Watz, Erik J., sales engr., Gen. Elec. X-Ray Corp., New York City.

18 to Grade of Member

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the address as it now appears on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Brayman, Chas. E., c/o J. J. Murphy & Son, 38 Ford St., Hartford, Conn.
Gilliam, Charles T., Power Cost Engg. Co., 742 Milam Bldg., San Antonio, Texas.
Goulding, Harold, 404 W. 116th St., New York, N. Y.
Gray, L. Tenney, Jr., 6452 Hillegas Ave., Oakland, Calif.
Henrichsen, E. E., Bell Tel. Labs. Inc., 463 West St., New York, N. Y.
McNitt, Donald P., 1009 First Natl. Life Bldg., St. Louis, Mo.
Miller, Frank D., Box 34, Yatesboro, Pa.
O'Handley, Joseph A. E., 579—61st St., Bklyn., N. Y.
Patton, Edgar P., Standish Arms, 169 Columbia Heights, Bklyn., N. Y.
Tamburello, G., 307 West 20th St., N. Y. City.
Thompson, B. F., Minas de Matahambre, Matahambre, Pinar Del Rio, Cuba.
Valier, Chas. E., Jr., 1804 Tel. Bldg., St. Louis, Mo.
Villegas, Tacoma General Hospital, Tacoma, Wash.

13 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

CALCULATION and DESIGN of ELECTRICAL APPARATUS. By W. Wilson. Lond., Sir Isaac Pitman & Sons, Ltd., 1934. 214 p., illus., 7x5 in., cloth, $3.00. Aims to provide a general, brief exposition of the principles that govern the calculation and design of switchgear, control gear, protective equipment, instruments and similar apparatus, as distinct from electrical machines and transformers. The work is presented in a practical manner.

DESIGN and USE of INSTRUMENTS and ACCURATE MECHANISM. By T. N. Whitehead. N. Y., Macmillan Co., 1934. 283 p., illus., 9x6 in., cloth, $3.50. While intended primarily for designers and users of instruments, many of the principles involved are applicable to mechanism as a whole, and especially to light machinery, such as carburetors and magnetos, governors, components of textile machinery and printing presses. The author discusses various types of errors which may be present, their causes and methods by which they may be remedied.

EINFÜHRUNG in die PHYSIK der GASENTLADUNGEN. By R. Seeliger. 2 ed. Leipzig, Johann Ambrosius Barth, 1934. 563 p., illus., 9x6 in., paper, 46 rm.; bound, 48 rm. A summary of our knowledge of the discharge of electricity in gases. Provides an account of the work done in this field, which is well designed to orient the worker concerning the latest discoveries.

(The) ELECTRIC HOME. By E. S. Lincoln and P. C. Smith. N. Y., Elec. Home Pub. Co., 1933. 454 p., illus., 9x5 in., paper $1.00; cloth, $2.00. A popular description of the ways in which electricity may be used in the home. Advice is given upon indoor and outdoor lighting, electric appliances, wiring, etc. The book suggests many uses that are unfamiliar to most laymen.

ELECTRICAL TECHNOLOGY. By W. L. Horwood. Phila., J. B. Lippincott Co., 1934. 347 p., illus., 8x5 in., cloth, $5.00. Designed to meet the requirements for the graduateship examination of the Institution of Electrical Engineers (Great Britain), and intended for students familiar with the elements of magnetism and electricity. The fundamental theory, particularly a-c theory, has been emphasized and special attention is given to the development and use of vector diagrams.

ENTSTAUBUNGS- und LÜFTUNGFRAGEN in der WERKSTATT. By R. Nagel. Berlin, VDI-Verlag, 1934. 21 p., illus., 8x6 in., paper 1.80 rm. Presents the fundamentals of factory ventilation and dust removal in a concise, practical way. It is intended to give the factory manager a general view of the subject which will enable him to devise methods for his own needs.

Great Britain. Dept. of Scientific and Industrial Research. INDEX to the LITERATURE of FOOD INVESTIGATION. V. 5, No. 1, March, 1933, and No. 2, Sept., 1933. Lond. His Majesty's Stationery Office, 1934. 283 p., 10x6 in., paper, 5s. (Obtainable from the British Library of Information, New York, $1.43.) Approximately 100 periodicals are covered by this index, in addition to patents, books and reports. Brief abstracts and an author index are included, as well as an introductory review of developments during 1931 and 1932. The engineering section contains 366 references on temperature and humidity control, methods of food transport, insulation, refrigeration, air conditioning and gas producing.

Great Britain. Dept. of Scientific and Industrial Research. (Radio Research Report No. 14.) MAGNETIC MATERIALS at RADIO FREQUENCIES, by F. M. Colebrook. Lond., His Majesty's Stationery Office, 1934. 22 p., tables, 10x6 in., paper, 6d. (Obtainable from British Library of Information, N. Y., $17.) This brief survey covers present theoretical and experimental knowledge of iron-powder materials for coil cores. The available data about permeability, hysteresis, retardation loss and other losses are given, with a selected bibliography.

HANDBOOK of TECHNICAL INSTRUCTIONS for WIRELESS TELEGRAPHISTS. By H. M. Dowsett. 5 ed., rev. & enl. Lond., Iliffe & Sons, Ltd., 1934. 572 p., illus., 9x5 in., cloth, 15s. A theoretical course for students wishing to qualify for the certificate of proficiency granted by the postmaster general of Great Britain. The principles and practice of radio telegraphy are covered. While intended primarily for sea-going operators, the book will be useful to amateurs as well.

HISTORY of MATHEMATICS in AMERICA BEFORE 1900. (The Carus Mathematical Monographs No. 5). By D. E. Smith and J. Ginsburg. Chicago, published by Mathematical Assn. of Am. with the coöperation of the Open Court Pub. Co., 1934. 209 p., illus., 8x5 in., cloth, $2.00. A brief, readable survey of our mathematical achievements during the past, by a foremost American authority. The development of means for the study of mathematics, the influence of other countries, mathematical societies and periodicals and the achievements of prominent students are considered.

IMPACT TESTING of CAST IRON, Report of Subcommittee XV of Committee A-3 on Cast Iron. Phila., Am. Soc. for Testing Materials, 1934. 51 p., illus., 9x6 in., paper, $.50. This report by a committee of the A.S.T.M. discusses the usefulness of the several forms of impact test as applied to cast iron. An extensive program of tests formed the basis for the report, which contains the results and the conclusion of the committee.

INDUSTRIALIZED RUSSIA. By A. Hirsch. N. Y., Chem. Cat. Co., 1934. 309 p., illus., 8x6 in., cloth, $3.00. Presents pertinent facts about the present status of the chemical, metallurgical, agricultural, and other industries, and discusses business, government, law, living conditions, education, etc. A factual report by a sympathetic observer.

INTRODUCTION to MODERN PHYSICS. By F. K. Richtmyer. 2 ed. N. Y. & Lond., McGraw-Hill Book Co., 1934. 747 p., illus., 9x6 in., cloth, $5.00. Based upon lectures given at Cornell University to meet the needs of students who wish a survey of the origin, development, and present status of physics. Discusses the electromagnetic theory of light, the quantum theory, atomic structure, X rays, the wave theory of matter and other important developments.

MODERN POLYPHASE INDUCTION MOTORS, particularly those with Various Types of Single and Double Squirrel-Cage Rotors; tr. from the German by H. M. Hobart. By F. Punga and O. Raydt. Lond., Sir Isaac Pitman & Sons, 1933. 289 p., illus., 9x5 in., cloth, $5.00. Not a general textbook on the induction motor, but a discussion of the merits and advantages of the squirrel-cage type. The special windings and constructions that have been brought forward at various times to remedy the low starting torque of the type are reviewed.

Industrial Notes

Large Steel Mill Order to Westinghouse.—Amounting to nearly a million dollars, the largest single order for steel mill electrical equipment since 1929 was awarded to the Westinghouse Electric & Mfg. Company by the Mesta Machine Company. The electrical equipment, consisting of motors, control material, motor-generator sets, and auxiliary units, will be installed on a 76 inch strip mill being built by Mesta for the Youngstown Sheet & Tube Company. Wide strip steel, produced in the new mill, is used for automobiles but has a variety of other uses. Included in the order will be six 3,500 horsepower motors. Work on the order has begun in East Pittsburgh and it will be completed in less than six months.

New Consulting and Research Association.—According to a recent announcement 5 research engineers formerly employed in the Westinghouse research laboratories have formed a new company known as the Consulting and Research Association, at 823 Franklin Ave., Wilkensburg, Pa. The purpose of this organization is to provide a consulting, research, and development service to manufacturing companies. This organization includes research engineers who have specialized in the following subjects: air conditioning, heating, and ventilation, construction and application of electronic devices, oscillographs, television, electric circuits, radiography, mechanical design and application, and plant survey and layout. The need for such an organization, particularly for short time research problems confronting manufacturing companies without laboratory facilities, has long been recognized.

Delta Mfg. Co. Joins Raytheon.—Announcement has been made that the Delta Mfg. Co., formerly of Cambridge, Mass., makers of Acme-Delta transformers, chokes, and power equipment for radio amateurs, Delta high voltage rectifiers for broadcast stations, Delta voltage regulators, and other special power conversion equipment, has jointed the Raytheon Mfg. Co. The activities of the combined companies will be carried on under the name of Raytheon Mfg. Co., Electrical Equipment Division, in a newly acquired plant at 190 Willow St., Waltham, Mass. There has been no change in the Delta organization and all products formerly made by them will now continue to be manufactured by the same personnel and sold by Raytheon's electrical equipment division. In addition, new types of rectifying apparatus for converting alternating current into direct current are being designed to permit the use of rectifiers in industrial applications where previously only motor generators or storage batteries could be used. The Raytheon Production Corp., Raytheon Tube Division, continues as before with its manufacturing plant at Chapel St., Newton, Mass.

Single-Step Voltage Booster.—A low priced, pole mounted booster which automatically changes a feeder's voltage either 5% or 10% in a single step has been announced by the Westinghouse Electric & Mfg. Co. This new type B feeder voltage booster is particularly suitable for maintaining proper voltage for rural lines, isolated loads, or distribution circuits where the load changes once or twice daily from very light to practically full load.

New Across-the-Line Motor Starter.—The Electric Controller & Mfg. Co., Cleveland, O., announces type ZO, weather-proof and dust-tight, across-the-line, oil-immersed motor starter for motors up to 15 hp., 220 volt, and 30 hp., 440–550 volts. The starter is arranged for remote control, push button automatic operation. When desired, a self-contained ammeter in a dust-tight case is also furnished with the starter.

Combination Tester and Fuse Puller.—The Ideal Commutator Dresser Co., Sycamore, Ill., has developed a combination "Test-lite" and fuse puller. Made of reinforced Bakelite and resembling a pair of pliers, this new device combines a tool for testing, removing, or inserting fuses from 30 to 100 amperes, testing circuits of from 110 to 550 volts, and handling all types of current carrying electrical parts. The test pins are mounted on handle ends—opening or closing handle adjusts the pins to proper distance. The test light is enclosed in the handle. The tool is of pocket size, 7 inches long.

Trade Literature

Motors.—Bulletin 2173, 4 pp. Describes type AR squirrel cage induction motors, 1 to 75 hp. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Carbon Brushes.—Catalog 634. Describes brushes for single-phase and fractional horse-power motors. Helwig Co., 3466 S. 13th St., Milwaukee, Wis.

Aerial Cable.—Bulletin, 4 pp. Describes rubber insulated metallic and non-metallic sheathed aerial cable for overhead lines. General Cable Corp., 420 Lexington Ave., New York.

Street Lighting Cable.—Bulletin, 4 pp. Describes series street lighting cable, rubber insulated, "Thiokol" sheathed. General Cable Corp., 420 Lexington Ave., New York.

Laminated Bakelite.—Booklet describes laminated Bakelite in sheet, rod, tube, and other fabricated form. A distinctive feature of this booklet is that it contains actual samples of the material, enclosed in envelopes. The Synthane Corp., Oaks, Pa.

Battery Charging Rheostats.—Bulletin 2501, 4 pp. Describes battery charging rheostats and resistors, particularly suited for use where a number of different types of batteries are to be charged from the same direct current source. Prices are included. Ward Leonard Electric Co., Mt. Vernon, N. Y.

Transformer Manufacturer Moves.—The R. E. Uptegraff Mfg. Co., manufacturers of high-voltage power transformers, have moved to 300 N. Lexington Ave., Pittsburgh, Pa., where more than double the floor area of their former plant is provided. Recent production has necessitated double shifts.

Air Hoists.—Bulletin 12107, 32 pp. Describes "Utility" air hoists. The single-drum hoists are available in 10 sizes with capacities up to 2,000 lbs. straight line pull. The double-drum hoists are built in 4 sizes up to 2,000 lbs. capacity. A single lever controls all movements of the hoist. Ingersoll-Rand Co., 11 Broadway, New York.

Portable Instruments.—Bulletin 7, for catalog 123, 4 pp. Describes a new line of portable measuring instruments, types NPD and NPA, for general testing purposes. The NPD line includes direct current ammeters, voltmeters, milli-voltmeters and milli-ammeters of all ranges. The NPA types are a companion line of alternating current instruments. Roller-Smith Co., 233 Broadway, New York.

Insulated Cable.—Bulletin GEA-1837, 80 pp., "How to Select Insulated Cable." The more usual applications of cable are covered and there is presented in convenient form the information required for determining the cable best adapted for any particular installation. Two methods of selecting conductor size are given. The first, a comparatively simple one, covers cable for wiring buildings, small industrial plants, etc. The other method, more detailed, includes 27 tables of current-carrying capacities. General Electric Co., Schenectady, N. Y.

Lightning Arresters.—Bulletin 375, 160 pp. Describes Crystal Valve lightning arresters for both high and low voltage a-c service and for low voltage d-c service; tank type arresters, neutral arresters and coördinating gaps; Garton-Daniels lightning arresters for low voltage a-c and d-c service and for high voltage d-c railway service; ground testing equipment and ground fittings. Much technical information on the subject of lightning protection is included. Electric Service Supplies Co., 17th & Cambria Sts., Philadelphia, Pa.

Underground Conduit.—Bound data sheets, 12 pp., on the recently announced Transite electrical conduit, made of asbestos fiber and portland cement. The material is fireproof, highly corrosion-resistant and immune to electrolysis. Because of its unusually high mechanical strength it can be used as a cable subway without concrete covering. The sheets include full information on sizes, weights, and list prices, details and dimensions of fittings, illustrations of installation methods, etc. Johns-Manville, 22 E. 40th St., New York.